IRON AND STEEL INDUSTRIAL RESEARCH COUNCIL
TECHNICAL REPORT No. 1

COKE FOR BLAST FURNACES

FIRST REPORT OF
THE MIDLAND COKE
RESEARCH COMMITTEE

CENTRAL STORE

Mining Dept.

Author MIDLAND
Class Mark S/TP 336
Book No. 67791

QUÆRENTI OSTIUM

UNIVERSITY
OF NOTTINGHAM
LIBRARY
Science Library

UNIVERSITY COLLEGE,
MINING
DEPARTMENT
NOTTINGHAM.

61 0074153 9
TELEPEN

UNIVERSITY OF NOTTINGHAM
WITHDRAWN
FROM THE LIBRARY

Students and External Readers DATE DUE FOR RETURN	Staff & Research Students DATE OF ISSUE
UNIVERSITY LIBRARY 30 JUN 2007 ANN GGL 26	-1. MAR. 1972

Any book which you borrow remains your responsibility until the loan slip is cancelled

57-w

COKE FOR BLAST FURNACES

IRON AND STEEL INDUSTRIAL RESEARCH COUNCIL
TECHNICAL REPORT No. 1

COKE FOR BLAST FURNACES

Being the First Report of the
Midland Coke Research Committee

BY

R. A. MOTT

AND

R. V. WHEELER

UNIVERSITY COLLEGE LIBRARY NOTTINGHAM
JUL 3
1940

LONDON
THE COLLIERY GUARDIAN CO., LTD.
30–31 FURNIVAL STREET, E.C.4
1930

Printed in Great Britain by
Richard Clay & Sons, Limited,
BUNGAY, SUFFOLK.

PREFACE

The Midland Coke Research Committee was formed at the instance of Professor R. V. Wheeler of the Department of Fuel Technology, Sheffield University, with a view to extend the research work on the manufacture and properties of coke which had been in progress at the University for several years, and to discuss standard methods of coke testing. The first meeting of the Committee was held on February 4th, 1926, at which representatives of the Lincolnshire, the Midland and the Northamptonshire Ironmasters' Associations were present, arrangements for such a conference having been made by Mr. E. C. Evans, head of the Fuel Department of the National Federation of Iron and Steel Manufacturers. Professor Wheeler was supported by Professor Desch of the Department of Metallurgy, Sheffield University, and the Registrar of the University, Mr. W. M. Gibbons, was present to consider the necessary financial arrangements. The Midland and the Lincolnshire Ironmasters' Associations agreed to contribute to the cost of research work, and certain members of the Northamptonshire Ironmasters' Association agreed to grant financial aid as separate firms. Certain tentative methods of testing coke were agreed upon for trial, and it was arranged that samples of cokes of known blast-furnace value should be submitted to those tests. It was also agreed that the research work already in progress should be continued by Mr. R. A. Mott (Research Assistant, Department of Fuel Technology, Sheffield University) with the aid of two post-graduate research scholars of the University. Mr. Mott was also appointed local secretary of the Committee, with Mr. E. C. Evans as organising secretary. At a later date, additional research workers were engaged.

The Committee was subsequently enlarged by the addition of representatives from the South Yorkshire Coal Trade Association (as coke producers), the South Yorkshire Survey Committee of the Fuel Research Board, the Coke Oven Managers' Association, and the National Federation of Iron and Steel Manufacturers. Representatives from individual iron-producing firms who had agreed to contribute to the cost of the research work were also added.

The name of the Committee was originally "The Blast Furnace Coke Research Committee (Yorkshire and Derbyshire Coalfields)." This was subsequently changed for convenience to the present title.

The present constitution of the Committee is as follows :—

1. W. J. Brooke (Chairman), Messrs. John Lysaght, Ltd., Scunthorpe, Lincs.
   J. Crawford, N. Lincolnshire Iron Co., Ltd., Scunthorpe, Lincs.
   A. Crooke, Frodingham Iron & Steel Co., Ltd., Scunthorpe, Lincs.
2. H. H. Jackson, Clay Cross Co., Ltd., Chesterfield, Derby.
   R. Miles, Newton Chambers & Co., Ltd., nr. Sheffield, Yorks.
   R. Sharp, Stanton Ironworks Co., Ltd., nr. Nottingham, Notts.
3. S. J. Lloyd, Lloyds Ironstone Co., Ltd., nr. Kettering, Northants.
   G. H. Johnson, Kettering Coal & Iron Co., Ltd., Kettering; Northants.
4. T. W. Brameld, Park Gate Iron & Steel Co., Ltd., Rotherham, Yorks.
   T. H. Byrom, Wigan Coal & Iron Co., Ltd., Wigan, Lancs.
   J. S. Kerr, Partington Iron & Steel Co., Ltd., Irlam, Lancs.
   E. S. Grumell, Imperial Chemical Industries, Ltd., Winnington, Northwich, Cheshire.
   A. E. Hodgkin, Imperial Chemical Industries, Ltd., Millbank, S.W. 1.
   E. C. Evans (Co-ordinating Secretary), National Federation of Iron & Steel Manufacturers, Tothill St., S.W. 1.
5. A. Blenkinsop, Dalton Main Collieries, nr. Rotherham, Yorks.
   J. H. W. Laverick, Tinsley Park Colliery Co., Ltd., nr. Sheffield, Yorks.
   G. T. Purves, Rothervale Collieries, nr. Sheffield, Yorks.
   P. B. Nicholson, Cortonwood Collieries, Ltd., nr. Barnsley, Yorks.
6. J. Brass, Houghton Main Colliery Co., Ltd., nr. Barnsley, Yorks.
   R. Clive, Victoria Hotel, Sheffield, Yorks.
7. C. P. Finn, Manvers Main Collieries, Ltd., nr. Rotherham, Yorks.
   G. A. Hebden, South Yorkshire Chemical Works, Ltd., nr. Rotherham, Yorks.
8. C. H. Lander, Fuel Research Division, Department of Scientific and Industrial Research, 16, Old Queen Street, S.W. 1.
   J. E. Fletcher, British Cast Iron Research Association, 11, St. James' Road, Dudley, Staffs.
   H. V. A. Briscoe, Northern Coke Research Committee, Armstrong College, Newcastle-on-Tyne.
   W. Davidson, Scottish Coke Research Committee, Royal Technical College, Glasgow.
   L. Slater, Coal Survey Laboratory, Portobello Street, Sheffield.

9. { C. H. Desch, Department of Metallurgy, Sheffield University.
W. M. Gibbons (Treasurer), Sheffield University.
R. A. Mott (Local Secretary), Department of Fuel Technology, Sheffield University.
R. V. Wheeler, Department of Fuel Technology, Sheffield University.

1. Representing the Lincolnshire Ironmasters' Association.
2. Representing the Midland Association of Blast Furnace Owners.
3. Representing the Northamptonshire Blast Furnace Owners' Association.
4. Independent members.
5. Representing the South Yorkshire Coal Trade Association.
6. Representing the South Yorkshire Survey Committee of the Fuel Research Board.
7. Representing the Coke Oven Managers' Association.
8. Co-ordinating members.
9. Representing the University of Sheffield.

The broad lines of research are agreed upon by the Committee as a whole, and individual members supply cokes, of known origin and quality, for testing and experiment. The direction of the laboratory research work is in the hands of Professor Wheeler and his Research Assistant, Mr. R. A. Mott, and is carried out in the laboratories of the Departments of Fuel Technology and Metallurgy of Sheffield University, whilst several members of the Committee have been good enough to grant facilities for large-scale experimental work to be carried out at their works.

The Committee is in close touch with similar Committees (which were formed subsequently) in other districts, and arrangements have been made for inter-representation. The Midland Coke Research Committee is concerned with all cokes made from coals of the Yorkshire (including Derbyshire) Coalfield and with any cokes used by members of the Committee. The Northern Coke Research Committee, with headquarters at Newcastle-upon-Tyne, is concerned mainly with cokes made from coals in Cumberland and Durham. The Scottish Coke Research Committee is concerned with Scottish cokes. The results of our research work are circulated to all members of each of the committees as quarterly progress reports, which are confidential.

Financial support is now given by the Lincolnshire Ironmasters' Association, the Midland Association of Blast Furnace Owners, the Northamptonshire Blast Furnace Owners' Association, Messrs. Lloyds Ironstone Co., Ltd., Messrs. Stewart & Lloyds (Alfred Hickman & Co., Branch), the Park Gate Iron and Steel Co., Ltd., the Wigan Coal and Iron Co., Ltd., the Partington Iron and Steel Co., Ltd., the Blackwell Colliery Co., Ltd., and Messrs. Imperial Chemical Industries, Ltd. The South Yorkshire Coal Trade Association also contribute through the funds of the Mining and Fuel

Committee of Sheffield University. Individual coke-producing firms contribute indirectly by making special large-scale coke-oven tests. A £ for £ grant on the amount contributed by industry is made by the Department of Scientific and Industrial Research, whose grant is allocated through the Industrial Research Council.

The present report deals mainly with the results of work completed up to the end of 1929. Some of the results of later work are included where necessary.

The thanks of the Committee are due to the many firms who have assisted us by carrying out special tests at their works. In particular, we are indebted to Messrs. John Brown & Co., Ltd., the Rother Vale Collieries, Ltd., the Tinsley Park Colliery Co., Ltd., Messrs. Skinner & Holford, Ltd., and the Manvers Main Collieries, Ltd., who have carried out extended series of large-scale tests at their coke-ovens, and to the Trent Iron Co., Ltd., who have made special blast-furnace trials.

The staff of the Midland Coke Research Committee responsible for most of the experimental work described in this Report have been:

J. Hiles, M.Sc.	General testing and research.
R. G. Davies, B.Sc., Ph.D.	Laboratory study of the coking properties of coals.
R. W. Perry W. Frith	Coke analyses, density determinations, furnace tests and coke-oven tests ("box tests.")
J. E. Peake J. Hodgkinson	Sampling of coke, size analyses, shatter tests and abrasion tests.
W. Brewin	Coke sectioning and photography.
M. Beevor	Assistant to Dr. R. G. Davies.

N. A. Ross, employed during 1928–29, has left the staff to take up another appointment.

In addition, the thanks of the Committee are due to the following members of the Department of Fuel Technology of Sheffield University for their voluntary assistance: L. Burdekin, M.Sc.Tech., J. Diamond, B.Sc.Tech., F. Heathcoat, M.Sc., F. W. Middleton, H. Organ, E. W. Ramsay, B.Sc.Tech., T. Shimmura, F. Smith and T. G. Woolhouse, M.Sc., Ph.D.

(*Signed on behalf of the Midland Coke Research Committee*)
W. J. Brooke (*Chairman*).

May, 1930.

CONTENTS

PAGE

INTRODUCTION 1

Outline of the work of the Committee—Two main problems: The specification of coke qualities and the production of coke to conform with that specification—Programme of research.

PART I

THE SPECIFICATION OF BLAST-FURNACE COKE

CHAPTER I

THE QUALITIES TO BE SPECIFIED 11

The size of coke—The structure of coke: shape, fractures, cell-walls and pores—Chemical analysis—Real and apparent specific gravity—Abradability—Impact hardness—Reactivity and combustibility.

CHAPTER II

THE SIZE OF COKE 18

The effect of the coal charge on the size of coke: coking quality, size of coal, blending the coal charge—The effect of oven conditions on the size of coke: method of charging, rate of heating—The effect of handling after manufacture on the size of coke—The effect of attrition in the blast furnace on the size of coke.

CHAPTER III

THE STRUCTURE OF COKE 33

Macro-structure: shape, appearance, fractures—Micro-structure—Appendix.

CHAPTER IV

THE ANALYSIS OF COKE 55

Sampling—Pulverising coke for analysis—Moisture—Ash—Volatile matter—Sulphur—Nitrogen—Phosphorus—Arsenic—Carbon.

CHAPTER V

THE REAL, APPARENT AND BULK DENSITY OF COKE AND ITS POROSITY 64

Real specific gravity—Apparent specific gravity—Bulk-density.

CHAPTER VI

PAGE
THE ABRADABILITY OF COKE 73
British tumbler tests—American tumbler tests—German tumbler tests—French tumbler test—The development of a test of abradability of coke—Appendix.

CHAPTER VII

THE HARDNESS OF COKE 94
The shatter test—Sampling coke for shatter testing—Shatter indices of cokes—Appendix.

CHAPTER VIII

THE REACTIVITY OF COKE 117
Early observations on the reactivity of coke—Measurements of the reactivity of coke—The Midland Coke Research Committee's method of test—The combustion of a standard size of coke with a standard rate of supply of air—The combustion of a standard size of coke with different rates of supply of air—The combustion of different sizes of coke with the same rate of supply of air—The reactivity of coke in blast-furnace practice—Appendix.

CHAPTER IX

THE SPECIFICATION OF COKE 141
The chemical properties of cokes in relation to their specification—The hardness of coke in relation to its specification—Other properties of coke in relation to its specification.

PART II

THE MANUFACTURE OF BLAST-FURNACE COKE TO SPECIFICATION

CHAPTER I

THE INFLUENCE OF THE CHARACTER OF THE COAL . . . 153
The constitution of coal—Ultimate analyses of coals—Rational analyses of coals—Caking power—Stages in the formation of coke—The expansion of coal.

CHAPTER II

THE INFLUENCE OF BLENDING THE COAL CHARGE . . . 179
The blending of a caking coal with a caking coal—The blending of a coking coal with a low volatile non-caking coal—The blending of coking coals with low temperature coke—The blending of coking coals with fusain.

CHAPTER III

PAGE
THE INFLUENCE OF THE SIZE OF THE COAL 195

Graded sizes of coal—Through sizes of coal—The influence of the size of the coal on the density and porosity of the coke—The influence of the size of the coal on the reactivity of the coke—Summary.

CHAPTER IV

THE INFLUENCE OF THE METHOD OF CHARGING THE OVEN . 204

The influence on the size of the coke—The influence on the hardness of the coke—The influence on the density and porosity of the coke—The influence on the structure of the coke—The influence on the reactivity of the coke—A further comparison of "top-charged" and "cake-charged" cokes—Summary.

CHAPTER V

THE INFLUENCE OF MOISTURE 210

CHAPTER VI

THE INFLUENCE OF THE RATE OF HEATING THE OVEN . . 213

Average rates of heating—The influence on the size of the coke—The influence on the hardness of the coke—The influence on the density and porosity of the coke—The influence on the reactivity and combustion temperature of the coke—General considerations.

CHAPTER VII

QUENCHING, SCREENING AND HANDLING COKE 222

Quenching—Screening and handling.

CHAPTER VIII

METHODS OF RESEARCH ON BLAST FURNACE COKE . . . 228

Box tests—Bag tests—Experimental ovens—Blast-furnace trials.

APPENDIX

TABULAR RECORDS OF TESTS ON COKES EXAMINED BY THE MIDLAND COKE RESEARCH COMMITTEE 239

INDEX

NAME INDEX 257
SUBJECT INDEX 259

LIST OF PLATES

PART I.—THE SPECIFICATION OF BLAST-FURNACE COKE

PLATE — TO FACE PAGE

I. Longitudinal Fractures in Welsh Coke and Durham Coke as seen in Transverse Face exposed by Breaking 12

II. Longitudinal Fractures in Yorkshire Coke and Derbyshire Coke as seen in Transverse Face Exposed by Breaking 12

III. Longitudinal Fractures in South Wales and Durham Cokes seen in Cut and Infilled Faces . . . 14

IV. Longitudinal Fractures in South Yorkshire and Derbyshire Cokes seen in Cut and Infilled Faces . 14

V. Comparison of Coke raked from Tuyeres of Blast Furnace with Unused Coke 30

VI. South Wales Coke: Longitudinal and End Views . 34

VII. South Wales Cokes: External Views . . . 34

VIII. Durham Cokes: External Views 34

IX. Yorkshire Cokes: External Views 36

X. Derbyshire Cokes: External Views. . . . 38

XI. Effect of Bottom Heat on Shape of Coke . . . 38

XII. Effect of Rate of Heating on Coke Shape . . . 38

XIII. Coke from Oven Sole and Oven Top . . . 38

XIV. Coke from Oven Sole with Double Cauliflower End and Curved Fractures 38

XV. Effect of Blending Low-temperature Coke Breeze on Coke Structure: Cauliflower End Views . . 42

XVI. Effect of Blending Low-temperature Coke Breeze on Coke Structure: Longitudinal Views . . . 42

XVII. The Effect of Blending on Coke Structure: Sections 42

XVIII. Massive Coke produced by Blending Coking Coal with Anthracite Duff 44

XIX. Massive Cokes produced from Ground Hards . . 44

XX. Comparison of External Appearance of a Series of Cokes arranged in Order of Relative Hardness . 45

XXI. Comparison of Sections of Series of Cokes arranged in Order of Relative Hardness 47

XXII. Method of Making Coke Sections 54

XXIII. View of Finished Coke Section 54

PLATE TO FACE PAGE

XXIV. Appearance of Coke after Treatment in Drum Abrasion Apparatus for Various Periods 86

XXV. Comparison of Coke Raked from Tuyeres with Coke treated for ½ hr. in Drum Abrasion Test . . 86

XXVI. Structure of Cokes; to Illustrate the Relationship between the Hardness of Different Coke Sizes and the Degree of Fissuring 108

PART II.—THE MANUFACTURE OF BLAST-FURNACE COKE TO SPECIFICATION

XXVII. Plant Entities Isolated from Bituminous Coal . . 162

XXVIII. Block of Bituminous Coal, Barnsley Seam, showing Banding 162

XXIX. Microscopic Structure of Ingredients of Banded Bituminous Coal 162

XXX. Stages in the Formation of Coke 174

XXXI. The Influence of Blending Poorly Caking Coal on the Structure of the Centre-of-oven Ends of Cokes made at a Fast Rate of Heating 182

XXXII. Structure of Anthracite Blend Cokes . . . 184

XXXIII. Blocky but Friable Cokes made by Blending . . 184

XXXIV. Comparison of Structure of Cokes made from Slurry and Dry Dust 190

XXXV. Structure of Hard Cokes Produced by Blending with Fusain and Fusain Substitutes 192

XXXVI. Improvement of Derbyshire Coke by Top-charging and Blending with Fusain 194

XXXVII. Effect of Graded Coal Size on the Structure of Coke . 196

XXXVIII. Effect of Pieces of Shale in Initiating Fractures in Coke 200

XXXIX. Comparison of Shape of Coke made from Top-charged and Cake-charged Coal (South Yorkshire) . . 206

XL. Comparison of Shape of Coke made from Top-charged and Cake-charged Coal (Cumberland) . . . 206

XLI. Comparison of Fracturing of Cokes made from Top-charged and Cake-charged Coal (South Yorkshire) . 206

XLII. Comparison of Fracturing of Cokes made from Top-charged and Cake-charged Coal (Cumberland) . 206

XLIII. Comparison of Structure of Cokes made from Different Types of Coal in 14-in. Ovens 216

XLIV. Structure of Coke made from Yorkshire Top-charged Coal at Different Rates of Heating . . . 218

XLV. Structure of Derbyshire Cokes made from Top-charged Coal at Different Rates of Heating . . . 218

XLVI. Views of Experimental Oven 232

LIST OF FIGURES

PART I.—THE SPECIFICATION OF BLAST-FURNACE COKE

FIG. PAGE

1. Transverse Fractures in Coke 13
2. Longitudinal Fractures in Coke 14
3. Shatter-test Results for Cokes made from Different Sizes of Coal 23
4. View of Coke on Top of a Wagon on Arrival at a Blast-furnace Plant 26
5. View of same Wagon of Coke through the Side Door . . 26
6. The Effect of Twelve Successive 6-ft. Drops on Three Cokes . 29
7. Shrinkage Cracks in Mud at Birchenlee Reservoir . . . 34
8. Shrinkage Cracks in Wall of Coke pushed out on to a Flat Bench 35
9. Diagram illustrating Curvature of Coke Shape caused by Shrinkage at Right Angles to Isothermal Lines which are not parallel to the Oven Wall 36
10. Curvature in South Wales Coke 37
11. Effect of the Addition of Low-temperature Coke Breeze on the Swelling Properties of the Blend, compared with the Hardness of the Coke produced 41
12. Transverse Section of Much-fractured Coke . . . 45
13. Comparison of Fracturing of Coke made from Top-charged and Compressed Coal 46
14. Comparison of Fractures of Cokes made from Straight Coal and a Blend with Low-temperature Coke Breeze . . 47
15. Micro-structure of South Wales Coke 48
16. Micro-structure of Durham Coke 49
17. Micro-structure of S. Yorkshire Coke, No. 3 50
18. Micro-structure of S. Yorkshire Coke, No. 4 51
19. Six-inch Era Manganese-steel Mortar and Pestle for Pulverising Coke 59
20. Earlier Apparatus for the Determination of the Apparent Specific Gravity of Coke 68
21. Apparatus for the Determination of the Real Specific Gravity of Coke 69
22. Cochrane's Tumbler Test Apparatus 74
23. A.S.T.M. Tumbler Test Apparatus 77
24. " Micum " Trommel Test Apparatus 81

FIG. PAGE
25. Sheffield Drum Abrasion Test Apparatus 83
26. Diagram of True Abrasion Test Apparatus 92
27. Standard Shatter Test Apparatus 95
28. Standard Shatter Test Apparatus in Use 96
29. Screening after Shatter Testing, showing Type of Screen and Method of Handling 97
30. Graph showing Relationship between Shatter Indices at Different Screens for a Number of Representative Cokes . 102
31. Graph showing Relationship between 2-in. and 1½-in. Shatter Indices for Series of Cokes 106
32. Daily Size Analyses of Coke on Receipt at a Blast-furnace Plant 113
33. Howland's Series of Blast-furnace Results 119
34. Arend and Wagner's Diagram of Variation of Reactivity with Temperature 121
35. Diagram of Combustibility Furnace used by Haüsser . . 122
36. View of Combustibility Furnace used by Kreisinger . . 123
37. Diagram of Combustibility Furnace used by the Midland Coke Research Committee 124
38. General View of Furnace used by the Midland Coke Research Committee 125
39. View of Furnace showing Charging Door 126
40. Water-cooled Copper Sampling Pipe and other Furnace Details 127
41. Gas Sampler and Diagrammatic Scheme of Sampling . . 128
42. Diagrammatic Representation of Simultaneous Sampling of Gases from Different Levels in Fuel-bed 129

PART II.—THE MANUFACTURE OF BLAST-FURNACE COKE TO SPECIFICATION

43. Coal-band (Carbon-content : Hydrogen-content) . . . 155
44. Coal-band (Carbon-content : Oxygen-content) . . . 158
45. Comparison of Carbon-content of Coal with Shatter Index of Coke 170
46. Comparison of Carbon-content of Coal with Agglutinating Value of Coal 170
47. Per Cent. Alteration in Volume of Single Piece and of Column of Particles of Parkgate R.M. Coal heated to Different Temperatures 174
48. Diagram of Sheffield Laboratory Test for Studying the Contraction and Expansion of Coals 177
49. Adjustable Loading Boom to reduce Drop experienced by Coke on Loading into Wagons 226
50. Diagram of Box for Box Test 229
51. Experimental Oven 233

LIST OF TABLES

PART I.—THE SPECIFICATION OF BLAST-FURNACE COKE

CHAPTER I

THE QUALITIES TO BE SPECIFIED

TABLE PAGE

I. Average Size Analyses of Coke Received for Test . 12

CHAPTER II

THE SIZE OF COKE

II. Surface Area of Coke Pieces of Different Sizes . . 19

III. The Effect of Removing $1\frac{1}{4}$-in. Coke in Blast-furnace Practice 20

IV. The Effect of the Coking Quality of the Coal on the Size of the Coke 21

V. The Effect of the Size of Coal Charged on the Size of Coke Produced 22

VI. The Effect of Blending the Coal Charge on the Size of the Coke 24

VII. The Effect of the Method of Charging the Oven on the Size of the Coke 24

VIII. The Effect of the Rate of Heating on the Size of the Coke 25

IX. Breeze Formation at Ovens and on Loading . . 27

X. Size Analyses of Yorkshire Cokes as Delivered at a Blast-furnace Plant 28

XI. The Effect of Dropping Coke from Different Heights 29

XII. Breakage of Coke Caused by Successive Drops from a Height of 6 ft. 30

XIII. Breakage of Cokes Subjected to Abrasion Test . . 31

CHAPTER III

THE STRUCTURE OF COKE

XIV. The Effect on the Hardness of Cokes of Blending Non-coking Materials with a Coking Coal . . . 40

CHAPTER IV

THE ANALYSIS OF COKE

TABLE PAGE
XV. The Determination of Moisture in Lump Coke . . 56
XVI. The Determination of Moisture in Ground Air-dried Coke 56
XVII. The Effect on Ash-contents of Different Methods of Pulverising Coke 58
XVIII. The Effect on the Ash-contents of Coke of Grinding and of Stamping during Pulverisation . . . 58
XIX. Comparison of Carbon-contents of Cokes as Determined Directly and as Calculated 63

CHAPTER V

THE REAL, APPARENT AND BULK DENSITY OF COKE AND ITS POROSITY

XX. Comparison of Different Blast-furnace Fuels . . 64
XXI. Comparison of Cell Size of Cokes and their Percentage Porosities 66

CHAPTER VI

THE ABRADABILITY OF COKE

XXII. Screening after Tumbler Test 83
XXIII. The Effect on Abrasion of Varying the Free Space in the Drum 84
XXIV. The Effect on Abrasion of Size of Coke Pieces Tested . 85
XXV. Comparison of Order of Abradability of Cokes as given by True Abrasion and Drum Abrasion Tests . . 87
XXVI. Abrasion Indices of Cokes using (*a*) 25 lb. and (*b*) 1 cu. ft. Charges 89
XXVII. Cokes of Low Abrasion Index (Sheffield Test) . . 90

CHAPTER VII

THE HARDNESS OF COKE

XXVIII. Duplication of Results of Shatter Testing . . 99
XXIX. Average Deviation of Each Result of Shatter Test from Mean of Three 100
XXX. Shatter Tests on Cokes of Different Sizes . . . 100
XXXI. Shatter Indices of a Series of Cokes 103
XXXII. Comparison of Shatter Indices of Cokes Made in Ovens of Different Widths 104

TABLE PAGE
XXXIII. Comparison of Shatter Indices of "Blocky" and "Prismatic" Cokes of the Same Quality . . 105
XXXIV. Average Results of Shatter Tests on Coke of Different Sizes 107
XXXV. The Effect on its Hardness of the Position of Coke in the Oven (horizontally flued) 108
XXXVI. The Effect on its Hardness of the Position of Coke in the Oven (vertically flued) 109
XXXVII. The Effect on its Hardness of the Position of Coke in the Oven (horizontally flued) 110
XXXVIII. The Effect on its Hardness of the Position of Coke in the Oven (vertically flued) 110
XXXIX. The Results of Shatter Tests on Shattered Coke . 111
XL. Comparative Tests of Hardness of Coke at Ovens and at Blast Furnace 111
XLI. Size Analyses of Coke from Wagons at Blast-furnace Plant 112
XLII. Shatter Indices (1½ in.) of Series of Representative Cokes 114

CHAPTER VIII

THE REACTIVITY OF COKE

XLIII. Typical Record of "Combustibility" Test . . 130
XLIV. Distance from Grate for Oxygen Disappearance (Rate 3) 132
XLV. Reactivity of Cokes with Oxygen and Carbon Dioxide 134
XLVI. Cokes in Order of Maximum Temperature of Fuel-bed 136
XLVII. Average Temperatures of the Fuel-bed (1½ to 10½ in. Levels) 136
XLVIII. The Combustion of Standard Size Coke with Different Rates of Supply of Air 137
XLIX. The Combustion of Different Sizes of Coke with the Same Rate of Supply of Air 139

CHAPTER IX

THE SPECIFICATION OF COKE

L. The Influence of Moisture and Ash in Increasing Coke Consumptions 143

PART II.—THE MANUFACTURE OF BLAST-FURNACE COKE TO SPECIFICATION

CHAPTER I

THE INFLUENCE OF THE CHARACTER OF THE COAL

TABLE		PAGE
LI.	A Comparison of the Rank of a Coal with the Quality of its Coke	164
LII.	Analyses of Coals Used for Coking in Different Districts	165
LIII.	Comparison of Rational Analyses of Coals with the Quality of Coke Produced	167
LIV.	Comparison between Various Caking Indices of Coals and the Shatter Indices of their Cokes (Slater)	168
LV.	Percentage Increase in Volume of Cubes of Parkgate R.M. Coal on Heating	171
LVI.	Changes in Volume of Columns of Particles of Parkgate R.M. Coal on Heating	172
LVII.	The Contraction and Expansion of Different Coals in a Laboratory Coking Test	176

CHAPTER II

THE INFLUENCE OF BLENDING THE COAL CHARGE

LVIII.	Analyses of Some Low-volatile Non-caking Coals used for Blending in Coke Manufacture	180
LIX.	The Blending of Two or More Caking Coals	181
LX.	The Blending of Coking Coals with Low-temperature Coke	185
LXI.	Comparison of Cokes made from Slacks, Slurries and Crushed Large Coals	187
LXII.	Size Analyses of Coals Charged to Ovens	187
LXIII.	Percentages of Fusain in the Finer Sizes of Coal	188
LXIV.	The Blending of a Coking Coal with Finely-ground Low-temperature Coke	189
LXV.	The Blending of a Coking Coal with Coal Dust Rich in Fusain	189
LXVI.	Cokes made from Settled Slurry, from Dry Dust and from Slacks Blended with Dust	190
LXVII.	The Fusain-contents of Slurries and Dusts	191
LXVIII.	The Blending of a Coking Coal with Fusain	192
LXIX.	The Blending of a Coking Coal with Fusain	192

TABLE		PAGE
LXX.	The Blending of a Coking Coal with High-temperature Coke Dust	193
LXXI.	The Blending of a Poor Coking Coal with Fusain	194
LXXII.	The Effect of Top-charging a Derbyshire Coal Blended with Fusain	194

CHAPTER III

THE INFLUENCE OF THE SIZE OF THE COAL

LXXIII.	The Size of Coke made from Graded Sizes of Coal	196
LXXIV.	Average Shatter Indices of Cokes made from Graded Sizes of Coal	196
LXXV.	Size Analyses of Cokes made from Through Sizes of Coal	197
LXXVI.	Shatter Indices of Cokes made from Through Sizes of Coal	198
LXXVII.	Comparison of Coarse and Fine Crushing of Coal	198
LXXVIII.	Size Analyses of Crushed Coals as Charged in Different Districts	200
LXXIX.	The Influence of the Size of the Coal on the Density and Porosity of the Coke	201
LXXX.	The Influence of the Size of the Coal on the Reactivity of the Coke	202

CHAPTER IV

THE INFLUENCE OF THE METHOD OF CHARGING THE OVEN

LXXXI.	The Influence of the Method of Charging the Oven on the Size of the Coke	205
LXXXII.	The Influence of the Method of Charging the Oven on the Hardness of the Coke	206
LXXXIII.	The Influence of the Method of Charging the Oven on the Density and Porosity of the Coke	207
LXXXIV.	The Influence of the Method of Charging the Oven on the Reactivity of the Coke	208
LXXXV.	The Influence of the Method of Charging the Oven on the Quality of the Coke (Northern Coke Research Committee)	208

CHAPTER V

THE INFLUENCE OF MOISTURE

LXXXVI.	Comparison of Cokes made from Wet and Dry Coal	211

CHAPTER VI

THE INFLUENCE OF THE RATE OF HEATING THE OVEN

TABLE PAGE

LXXXVII. Rates of Heating in Coke Ovens 213

LXXXVIII. Size Analyses of Cokes from the Same Coals Coked in Ovens of Different Widths 215

LXXXIX. Shatter Indices of Cokes from the Same Coals Coked in Ovens of Different Widths 216

XC. Characteristics of Cokes made in 14-in. Ovens . . . 218

XCI. The Density and Porosity of Cokes made from the same Coal in Ovens of Different Widths . . . 219

XCII. The Reactivity and Temperature of Combustion of Cokes made from the Same Coal in Ovens of Different Widths 220

XCIII. Combustibility and Hardness of Cokes made in Ovens of Different Widths (Haüsser and Bestehorn) . . 221

CHAPTER VII

QUENCHING, SCREENING AND HANDLING COKE

XCIV. The Moisture-contents of Coke at the Ovens and at the Blast Furnaces 223

XCV. The Moisture-contents of Coke at the Ovens, Central Quenching 224

CHAPTER VIII

METHODS OF RESEARCH ON BLAST-FURNACE COKES

XCVI. A Comparison of Cokes made in Box Tests and in Large-scale Oven Tests 230

XCVII. A Comparison of Cokes made in Bag Tests and in Large-scale Oven Tests 231

XCVIII. A Comparison of Cokes made in an Experimental Oven and in a Full-scale Oven 232

COKE FOR BLAST FURNACES

INTRODUCTION

A STUDY of coke for blast-furnace purposes involves two main problems: The specification of the qualities of the cokes found to be most suitable; and the production of cokes to conform with this specification.

The Specification of Coke Qualities.—The specification of a coke for a given purpose implies the standardisation of tests to determine whether that specification is being met. A list of the tests designed to give information as to the qualities of different cokes is given later in this Report. Most of these tests are now being applied, and much data has already been accumulated by means of them regarding many varieties of cokes.

An important matter with regard to the specification of coke qualities, more particularly for the blast furnace, is the attempted correlation of the qualities of a given coke with its behaviour in practice. Observations with regard to this are now in progress.

The Production of Coke.—Although the production of cokes of specific qualities can be attempted on empirical lines in large-scale oven tests, such methods are costly and, until the fundamental factors underlying coke formation are understood, progress will be slow. It will be impossible, for example, to blend coals satisfactorily, or to adopt the most suitable methods of heating, until satisfactory laboratory tests can predict the behaviour of different coals on heating under different practical conditions. The basic knowledge required is that of the constitution of coal, with simple analytical methods for determining it. Secondly, it is necessary to know the behaviour of coal on heat treatment, and the reason for its behaviour, so that, finally, the methods for producing suitable cokes in practice can be accurately gauged.

A general scheme of research on the coking of coal can thus be conveniently divided into three groups, namely :—

Group I. On the constitution and properties of coal.
Group II. On the thermal treatment of coal.
Group III. On the production of commercial cokes.

GROUP I. THE CONSTITUTION AND PROPERTIES OF COAL

Accurate methods for the analysis of coal are essential. These may be considered under the following headings :—

Proximate Analysis.—The determination of moisture, ash and volatile matter. Some relationship has already been traced between the moisture-content of air-dried coal and its coking power (see *Fuel*, 1925, **4**, 469). This requires further study. Ash in coal has sometimes been held to improve the strength of the resultant coke, whilst pieces of flat shale, " dirt," as distinct from ash, are sometimes assumed to initiate fractures in coke. The higher the volatile-content of a coal the greater is the percentage removal of material from an oven on coking. From a constant volume of coal (as in a coke oven), one of high volatile-content will either yield a more porous, or a more shrunken (and thus more heavily fractured) coke than that resulting from a low-volatile coal. Hence the contents of volatile matter of a coal should be correlated with the structure of the cokes produced at different rates of heating.

Ultimate Analysis.—The determination of carbon, hydrogen, sulphur, nitrogen and phosphorus. The direct determination of oxygen. It is known that a rough relationship exists between the carbon-content (or oxygen-content) of a coal and its coking power. It is probable that the oxygen-content is the more important factor. A direct method of determination of oxygen is necessary in order to study this satisfactorily.

Rational Analysis.—The more recent methods of " unbuilding " coal in order to study its constitution have been of great use in correlating its chemical composition with such properties as its liability to spontaneous combustion and the degree of inflammability of its dust. It is to be expected that similar methods will be of equal value in relation to the coking of coal. The methods of rational analysis employed result in the division of the coal into: (*a*) hydrocarbons; (*b*) resins; (*c*) recognisable plant remains; and (*d*) ulmins. The hydrocarbons and resins (part of the γ-compounds of coal) may be assumed to play an important part in binding coal particles together during coke formation, and they contribute much of the tar produced on carbonisation. Deficiency in quantity (as regards coke formation) of hydrocarbons and resins may occur only in steam coals and anthracites of high carbon-content, but the quality (or thermal stability) of these binding agents may not be satisfactory in coals of low carbon-content. On the other hand, the nature of the surfaces which the binding agents have to " wet " may be the dominant factor for most coals with respect to the strength of the cokes that can be produced from them. Small quantities of binding agent appear to be able to effect the preliminary binding in some South Wales coals, and from this and other data it is agreed that a low oxygen-content of the surfaces to be " wetted " is desirable. Hence the necessity for close study of that portion of the coal of highest oxygen-content, namely the ulmins. The ulmins constitute by far the largest part of the coal substance. It is the ulmin portion (and not the binding material) of a coal which is liable to oxidation on storage, an oxidation which with certain coals may considerably reduce their coking power. Finally, the plant remains which can be isolated from coal, namely spore exines and cuticles, are known to produce large quantities of tar on thermal decomposition, and must therefore be taken into account, in addition to the resins and hydrocarbons, as possible contributors to the process of coke-formation.

It is therefore desirable to know, for a series of representative coking coals from different coalfields, the amounts of (*a*) hydrocarbons, (*b*) resins, (*c*) plant remains and (*d*) ulmins which they contain, and the liability of their ulmins to oxidation. Methods for obtaining this information have been perfected.

Fundamental to the study of coke-formation is knowledge of the phenomena of " wetting " or adhesion, and of the relationship between chemical and physical composition and adhesion, cohesion, surface tension, adsorption and other related phenomena. Evidence has been obtained that oxidation reduces the activity of coal surfaces, the " wettability " being reduced and binding during coke formation hindered or altogether prevented. Sometimes an oxidised coal, or one normally of high oxygen-content, may be admixed with advantage with a high volatile coking coal to act as a " bubble burster," so as to make the resulting coke denser.

GROUP II. THE THERMAL TREATMENT OF COAL

The thermal stability of the binding material may not be such as to allow of the production of a satisfactory coke. It is therefore important to know over what temperature range the binding material becomes available to wet the surfaces of the coal particles. Moreover, swelling of the coal (due to decomposition and the production of gas), whereby adjacent coal surfaces are brought within the range of the molecular forces of cohesion, appears to be a necessary preliminary to satisfactory wetting. Hence it is necessary to know the temperature at which the main portion of the coal material, the ulmin portion, decomposes and the rate at which gas is produced. As the range of temperatures over which binding material becomes available (and during which preliminary decomposition of the coal ulmins occurs) appears to vary with different rates of heating, the rate of heating must be standardised within limits which are practicable in coke-oven practice. The thermal decomposition of coal may therefore be studied by the following methods :—

(1) The heating of coal at very slow rates in a vacuum to obtain the maximum yields of oil and to define the temperature ranges over which different types of oils are produced. These oils may then be compared with the oils extractable from the coal at low temperatures by solvents.

(2) The heating of coal at from 1 to 5° C. per minute (the limits possible in practice), to study the oil and gas yields over different temperature ranges for comparison with (1).

(3) The heating of coal to different temperatures (below 500° C.) at specified rates of heating, to study the extent of binding at

different temperatures and to compare the amounts of oil (*a*) liberated within the coal at these low temperatures (and extractable by solvents), and (*b*) distilled from the coal. The swelling of the coal can be measured and the extent of binding judged by the liability of the coke produced to abrade in a standardised abrasion test.

(4) The measurement of the resistance of coal to gas passage at different rates of heating under specified conditions. This determines the " plastic limits " of the coal and the maximum (or average) resistance, which may be a measure of the extent of binding (Foxwell's method, *Fuel*, 1924, **3**, 122).

(5) The determination of the temperature at which initial plasticity begins, with microscopical examination of the coked products (Audibert's method, *Fuel*, 1927, **6**, 131).

In methods 1, 2 and 3 the oils produced may be divided into bases, acids and neutral oils, or may be further subdivided by solvents in accordance with the methods described for study of the constitution of coal under Group I.

In these methods of examination the coal may be free to expand, but in practice coke is produced under constant volume conditions. Hence it is necessary to know whether any difference results when expansion is prevented, and the force with which the coal tends to expand should be determined.

Almost as important as the structure of the coke are the thermal yields of gas, of tar and other by-products. These should be related to the rational analysis of the coal, to enable them to be predicted without recourse to expensive large-scale trials.

Group III. The Production of Commercial Cokes

The production of suitable cokes will be expedited by the knowledge gained from the researches described in Groups I and II. In particular, it will be possible to suggest an optimum rate of heating for a given coal, and to forecast the results of blending different coals. Apart from blending, the variations in practice which the coke-oven operator can make to vary the quality of coke produced relate to: (*a*) The mode of charging (compressed or top-charged); (*b*) the moisture-content of the coal charged; (*c*) the degree of fineness of the coal used; and (*d*) the rate of heating (by choice of width of oven and temperature of heating flues). In order to test the effect of most of these variations, large-scale trials are required, but the most important variation—namely, the blending of the coal—cannot be used to the best advantage without the knowledge to be obtained from the researches in Groups I and II.

A considerable amount of useful information is likely to be gained by a microscopical examination of cokes made from coals from different coalfields, with a view to relate the number and size of pores, the thickness of cell walls and the number of broken cell walls in unit area of the coke to the chemical composition of the coal. By using one variety of coal, and gradually adding increased percentages of other coals to it to form blend cokes, the effect of blending on cell-structure can be directly studied.

Research Programmes

The researches necessary for a complete study of the coking of coal are here listed merely, with an occasional note in explanation, no attempt being made to detail methods of study. Those problems which are being systematically studied either by ourselves or by the organisations with which we are associated, namely, the Department of Fuel Technology of Sheffield University, the Fuel Research Board and the Safety in Mines Research Board, are marked with an asterisk.

Group I. The Constitution and Properties of Coal.

Programme No.		
C.C.1.	Proximate analysis.	Volatile matter.
C.C.2.	,, ,,	Ash.
*C.C.3.	Ultimate analysis.	Carbon and hydrogen.
*C.C.4.	,, ,,	Nitrogen.
*C.C.5.	,, ,,	Sulphur.
*C.C.6.	,, ,,	Oxygen.
*C.C.7.	,, ,,	Phosphorus and arsenic.

The methods of commercial analysis of coal are under review by a Committee of the B.E.S.A. In the meantime, the standard methods recommended by the Sampling and Analysis of Coal Committee of the Fuel Research Board seem satisfactory.

Most importance, from the point of view of specifying the characteristics of a coal, attaches to the ultimate analysis, in particular as regards (*a*) corrections with respect to mineral matter present in the coal, and (*b*) the direct determination of oxygen. Both subjects are being studied in the laboratories of the Department of Fuel Technology, Sheffield University.

Programme No.		
*C.C.8.	Rational analysis.	Hydrocarbons.
*C.C.9.	,, ,,	Resins.
*C.C.10.	,, ,,	Plant remains.
*C.C.11.	,, ,,	Ulmins.
*C.C.12.	,, ,,	The reactivity of the ulmins.
C.C.13.	,, ,,	Sulphur compounds.
C.C.14.	,, ,,	Nitrogen compounds.

The methods of rational analysis of coal have been standardised by the Safety in Mines Research Board and applied by them to a series of coals with respect to their liability to spontaneous combustion. The South Yorkshire Survey Committee of the Fuel Research Board have also applied these methods of rational analysis to a few coking coals. A wider range of coals is now being studied in the Fuel Department of Sheffield University.

Programme No.		
C.C.15.	Physico-chemical properties.	The "wettability" of coal by resins and hydrocarbons.
*C.C.16.	,, ,, ,,	The effect of oxidation.
*C.C.17.	,, ,, ,,	The effect of preheating.

The effects of oxidation and of preheating are being studied in the Fuel Department of Sheffield University in relation to coke formation during low-temperature carbonisation. Similar methods can be applied to the problem of coke formation during high-temperature carbonisation.

Group II. The Thermal Treatment of Coal

Programme No.		
*T.T.1.	Thermal treatment.	Distillation in a vacuum.
T.T.2.	,, ,,	Variation in rate of heating.
*T.T.3.	,, ,,	The determination of the plastic range.
*T.T.4.	,, ,,	The determination of the softening-point.
*T.T.5.	,, ,,	The determination of (*a*) the expansion range, and (*b*) the force of expansion.

Carefully regulated distillations in a vacuum, for a limited number of coals, have been carried out by the Safety in Mines Research Board with a view to determine the temperatures of decomposition and the character of the gaseous, liquid and solid products. The results are correlated with those obtained under Rational Analysis programmes C.C.8, C.C.9, C.C.10 and C.C.11. This work is now being extended by us to other coals, coking coals in particular.

Determinations of the plastic ranges and of the softening points of a series of coals have been made in the Fuel Department of Sheffield University. Similar work is now undertaken by the Midland Coke Research Committee.

Programme No.		
*T.T.6.	Thermal treatment.	The determination of "caking-power."
*T.T.7.	,, ,,	Correlation of caking-power with coking properties.

A study of methods of determining "caking-power" is being made by the South Yorkshire Survey Committee of the Fuel Research Board.

All the foregoing problems are concerned with measurement of the physical phenomena during coke formation, several different methods of attack being employed because of the complexity of the problem. The physical data thus obtained should be correlated with the results of the various researches in Group I. From data already collected it would appear that the swelling power of a coal, the resistance to gas passage during plasticity and the expansive force developed are related to the ease of escape of gas rather than to the rate of gas production. The ease of escape of gas is, in turn, no doubt related to the formation of liquid products and to the "wettability" of the coal surfaces by these liquid products.

Programme No.
*T.T.8. Thermal treatment. The effect of preheating.

Known temperatures within the plastic range should be employed, study being made of the changes produced in the character of the coke by the amounts of oil available for wetting.

Programme No.
*T.T.9. Thermal treatment. The formation of carbon.

The different types of carbon deposited on the coke surfaces during different conditions of heating should be studied and the effect of the deposition of these different types of carbon on the reactivity of the coke should be measured.

A preliminary study has been made, in the Fuel Department of Sheffield University, of the forms of carbon produced by the thermal decomposition of hydrocarbons. This is being extended.

Programme No.		
T.T.10.	Thermal treatment.	Correlation of yields of gas and tar with rational analysis.
T.T.11.	,, ,,	Exothermic and endothermic reactions during thermal treatment.
T.T.12.	,, ,,	The effect of mineral matter on the yields of by-products.

Group III. The Production of Commercial Cokes

(a) *Coke Production*

Programme No.		
*C.P.(a) 1.	Coke production.	The effect of oven width.
C.P.(a) 2.	,, ,,	The effect of flue temperature.
*C.P.(a) 3.	,, ,,	The effect of methods of charging.
*C.P.(a) 4.	,, ,,	The effect of size of coal.
C.P.(a) 5.	,, ,,	The effect of moisture in the coal.
*C.P.(a) 6.	,, ,,	The effect of ash (and of free dirt) in the coal.
C.P.(a) 7.	,, ,,	The effect of prolonging heating of charge beyond burning time.
*C.P.(a) 8.	,, ,,	The effect of blending normal coking coal with: (i) Coke breeze (both from low and high-temperature carbonisation); (ii) anthracite; (iii) low oxygen "non-coking" coals; (iv) high oxygen "non-coking" coals; (v) oxidised coals; (vi) preheated coals.
*C.P.(a) 9.	,, ,,	The effect of blending different coking coals: (i) From the same coalfield; (ii) from different coalfields.

(b) *Coke Properties*

C.P.(b) 1.	Proximate analysis.	Moisture.
C.P.(b) 2.	,, ,,	Volatile matter.
C.P.(b) 3.	,, ,,	Ash.
C.P.(b) 4.	Ultimate analysis.	Carbon and hydrogen.
*C.P.(b) 5.	,, ,,	Nitrogen.
C.P.(b) 6.	,, ,,	Sulphur.
*C.P.(b) 7.	,, ,,	Phosphorus and arsenic.

Methods of analysis of coke have not yet been standardised. Modifications of the methods of analysis used for coal are necessary.

Programme No.		
C.P.(b) 8.	Rational analysis.	Character of ash.
C.P.(b) 9.	,, ,,	Sulphur compounds.
C.P.(b) 10.	,, ,,	Phosphorus compounds.
C.P.(b) 11.	,, ,,	Carbon compounds and forms of carbon.
*C.P.(b) 12.	Physical properties.	(i) Bulk density; (ii) apparent specific gravity; (iii) real specific gravity; (iv) percentage total porosity; (v) percentage apparent porosity.
*C.P.(b) 13.	,, ,,	Macroscopic examination.
*C.P.(b) 14.	,, ,,	Microscopic examination.
*C.P.(b) 15.	,, ,,	Mechanical strength. Shatter test. (Impact hardness.)
*C.P.(b) 16.	,, ,,	Mechanical strength. Abrasion test. (Abrasion hardness.)
C.P.(b) 17.	,, ,,	Mechanical strength. Resistance to compression.
*C.P.(b) 18.	Combustion.	Rate of combustion. Combustion temperatures.
*C.P.(b) 19.	,,	Reactivity towards carbon dioxide.
C.P.(b) 20.	,,	Reactivity towards steam.
C.P.(b) 21.	,,	Ignition temperatures.
C.P.(b) 22.	,,	Clinker formation.

The researches on the combustion of cokes require to be correlated with their behaviour during industrial and domestic use.

This programme forms the basis of the work of the Midland Coke Research Committee. It has been adopted, in general principle, by the Northern and Scottish Coke Research Committees.

PART I

THE SPECIFICATION OF BLAST-FURNACE COKE

CHAPTER I

THE QUALITIES TO BE SPECIFIED

CERTAIN qualities of coke, which confer on it special value, are sometimes held to defy specification. Actually, the specification of the properties of coke does not present much difficulty. The difficulty begins when an attempt is made to correlate these properties with the behaviour of the coke in blast-furnace practice, for there are, as yet, insufficient data obtained systematically under carefully regulated conditions.

The principal qualities of coke that would appear to affect its behaviour in the blast furnace relate to its purity, its hardness and its combustibility. Except perhaps as regards the qualities relating to purity, the determination of the properties of coke involves the use of empirical tests, each detail of which requires to be carefully standardised. One of our first duties has been the standardisation of such tests.

The properties of coke that have been suggested as of prime importance are its size and structure, its chemical analysis, its real, apparent and bulk density and porosity, its abradability, its impact hardness and its reactivity with oxygen and carbon dioxide. Other properties which have from time to time been specified are now considered to be unimportant. For example, the absolute value of the crushing strength of coke would seem to be of little moment, for the stress to which coke is subjected during its passage down a modern blast furnace rarely exceeds 30 lb. per sq. in., a value well below the crushing strength of the weakest cokes.

The Size of Coke.—The size of coke is usually specified by reference to the size of square-mesh screen through which it passes or on which it rests after thorough shaking. The amount of shaking sufficient to cause each side of a small particle of coke to come into contact with a screen aperture is not enough for larger particles of more than about 1½-in. diameter. For this and larger sizes equivalent screening efficiency is obtained only when each oversize piece is handled and tested to see whether there is any one position in which it can pass through the screen aperture. The size specified in this way does not necessarily bear any relation to the length of the coke pieces (and thus to the oven width), but is governed by the maximum cross-sectional dimension. Since pieces of coke are usually of nearly square cross-section, a size analysis is a rough guide to their thickness or "blockiness."

The results of a size analysis of a consignment of coke can be expressed either as percentage amounts remaining on each of a series of screens of decreasing size of aperture, or as cumulative percentages for a series of screens. Both an upper and a lower limit of size have been suggested in practice. In America, for example, it is common to break down pieces larger than about 4 in., whilst the lower limit is from 1½ in. to as little as ¾ in. In Great Britain it is not customary to fix a maximum for the size of coke, so that the size analysis is best expressed by the cumulative values. We have made such size analyses on each consignment of coke received for test at the laboratories. Typical results are recorded in Table I.

TABLE I.—AVERAGE SIZE ANALYSES OF COKES RECEIVED FOR TEST

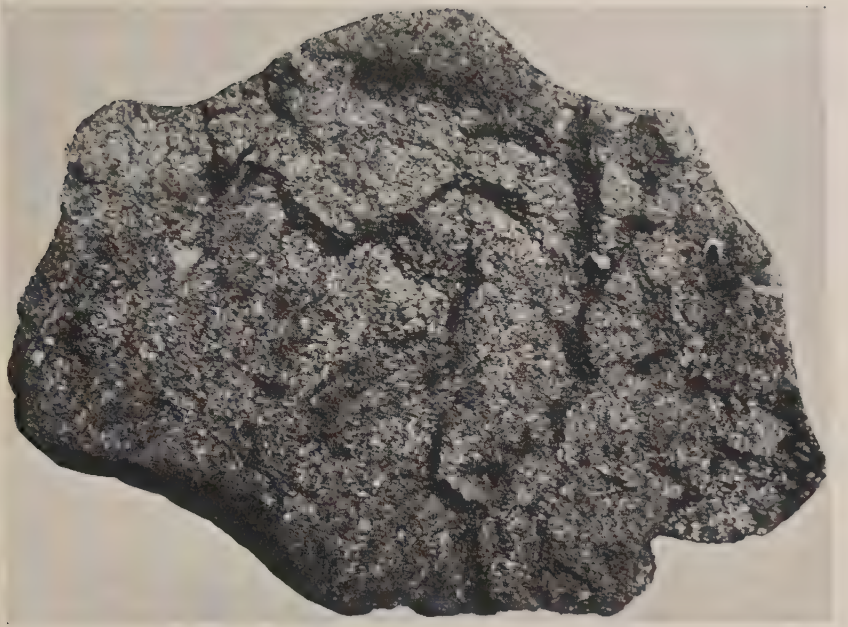
Coke No.	Origin.	Per cent. by weight remaining on screens of different aperture.					
		4-in.	3-in.	2-in.	1½-in.	1-in.	½-in.
39	South Wales.	64·6	86·5	95·6	97·9	98·5	98·9
30	Durham.	46·2	76·8	92·0	96·0	97·5	98·4
17JL	South Yorkshire.	30·5	55·7	78·2	88·1	95·0	—
33	,, ,,	9·1	26·3	59·4	77·0	89·2	—
22F	Derbyshire.	18·7	31·5	62·0	78·6	90·1	95·6

The Structure of Coke.—The qualities of coke included within the term " structure " are its shape, the degree and character of its fissures or fractures, and the character of its cell-walls and pores.

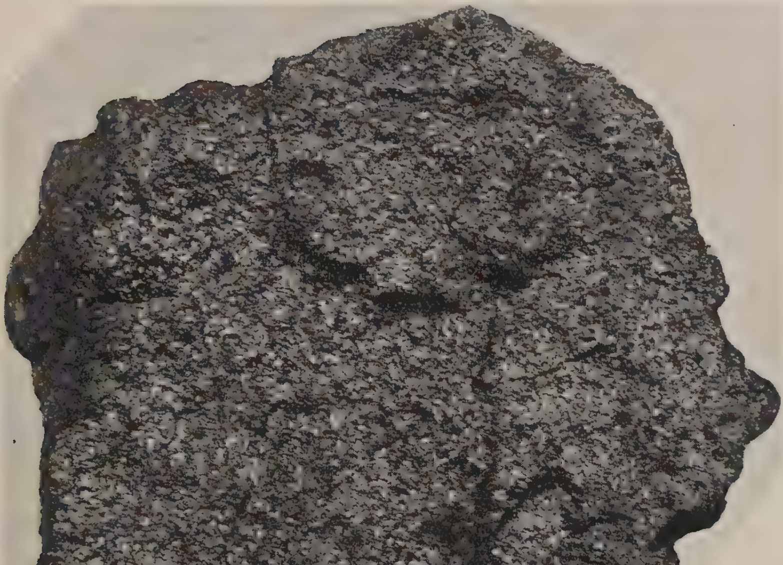
Shape. As discharged at the ovens, the best metallurgical cokes have regular rectangular outlines longitudinally and fairly regular hexagonal cross-sections, with well-curved cauliflower ends. Cokes made from low volatile (*e.g.* South Wales) coals usually have rough, granular surfaces and are of rather dull appearance. Cokes made from coals of higher volatile matter content (*e.g.* Durham) usually have a smooth surface and a light grey colour. A poor metallurgical coke is usually of irregular shape and often has curved outlines, the cross-section varying in area throughout the length of the piece. Such a shape causes the coke pieces to be weaker in some parts than in others, so that they break more readily than pieces of regular shape.

A coke of large cross-sectional area in relation to its length is said to be " blocky," whilst one of small cross-sectional area is referred to as " fingery " or " prismatic." The shapes of coke pieces are most conveniently recorded by photographs, and their tendency to be blocky or prismatic can be emphasised by noting the average dimensions of typical pieces.

Fractures. Fissures are to be found in nearly all cokes. For the most part, longitudinal fissures predominate, but in some cokes (*e.g.* in many Durham cokes) there are transverse fissures (see Fig. 1).



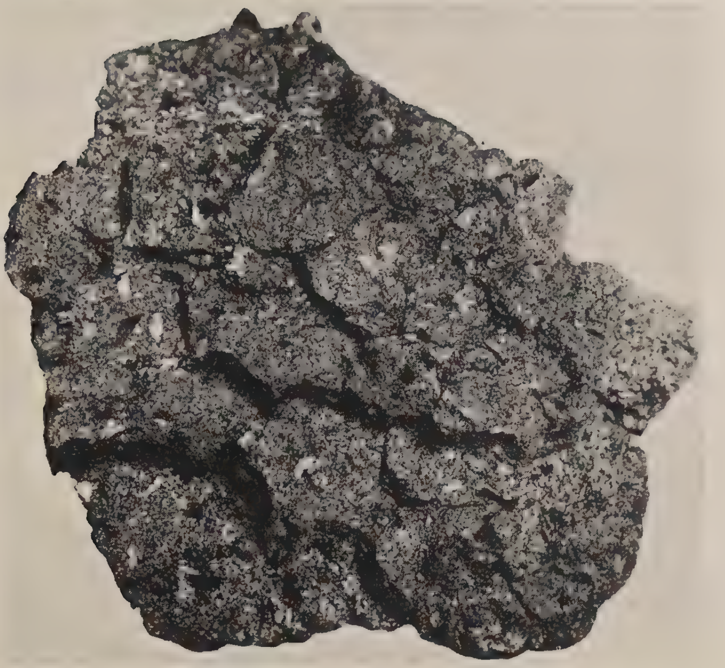
No. 43.



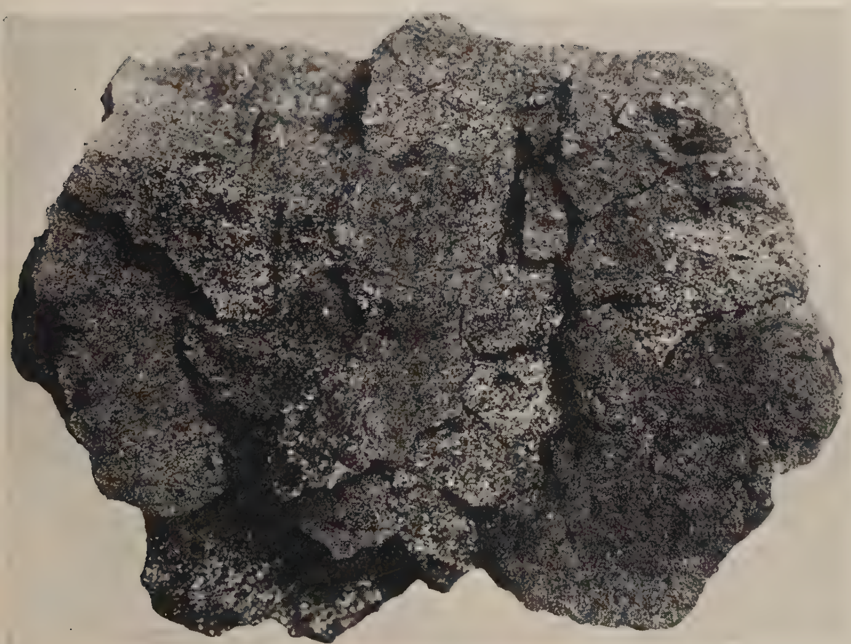
No. 30B.

PLATE I.—Longitudinal Fractures in Welsh Coke (above) and Durham Coke (below) as seen in Transverse Face Exposed by Breaking.

[*To face p.* 12.



No. 44.



No. 45A.

Plate II.—Longitudinal Fractures in Yorkshire Coke (above) and Derbyshire Coke (below) as seen in Transverse Face Exposed by Breaking.

[*To face p.* 12.

These are not usually as deep as the longitudinal fissures, and are therefore not so detrimental to the quality of the coke. Longitudinal fissures result from shrinkage during the formation of the coke in the oven, and are therefore more prevalent in cokes made from high-volatile coals (*e.g.* Derbyshire) than in those made from low-volatile coals (*e.g.* South Wales). Longitudinal fractures usually extend throughout the whole length of a piece of coke and, since they frequently occur in two planes, tend to isolate portions of it. An end view therefore shows a piece of poor-quality coke to be divided into a number of smaller pieces (see Fig. 2).

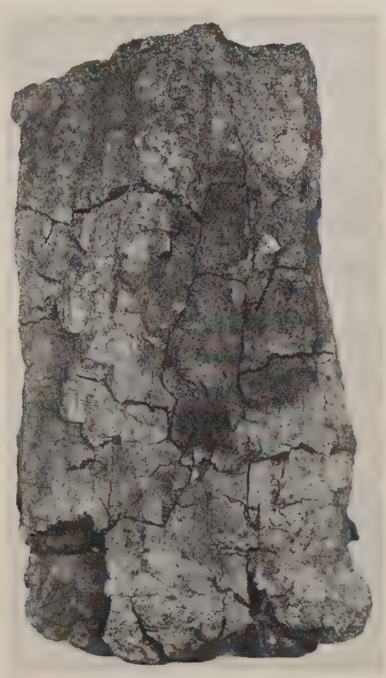


FIG. 1.—Transverse Fractures in Coke (Durham, No. 41).

Such fractures are often referred to as "cross-fractures," because they are readily recognisable when a piece of coke is broken across, but they should be distinguished from the transverse fractures which may occur at right angles to the length of the piece. In this Report the unqualified term "fractures" is used for the longitudinal fissures. As already stated, the fractures are disclosed when a full-length piece of coke is broken across. This can be done at the oven bench, for example, and a simple test of this kind often provides valuable information as to the quality of a coke. Typical fractures of a series of cokes are illustrated on Plates I and II. Whilst such a visual examination of a broken cross-section of coke suffices for the grosser fractures, small differences in the character of the fracturing are not readily observed. A section of coke made by means of a hack-saw or a carborundum wheel has a flat surface which renders examination easier, but the fractures are most clearly disclosed by the method devised by Rose (*Journ. Ind. Eng. Chem.*, Sept. 1925), whereby the fractures on a cut face of the coke are in-filled by a white composition. Examples of such preparations for the same series of cokes as on Plates I and II, are illustrated on Plates III and IV.

We have used Rose's method of examination, a full description of which is given later, for all the cokes submitted to test, and it has proved of considerable value. In general, the number, distinctness and extent of the fractures give a good indication of the liability of the coke to break during handling and transport.

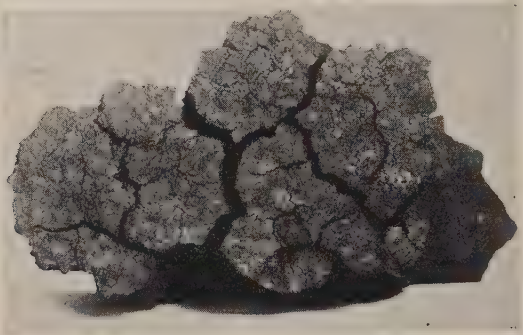
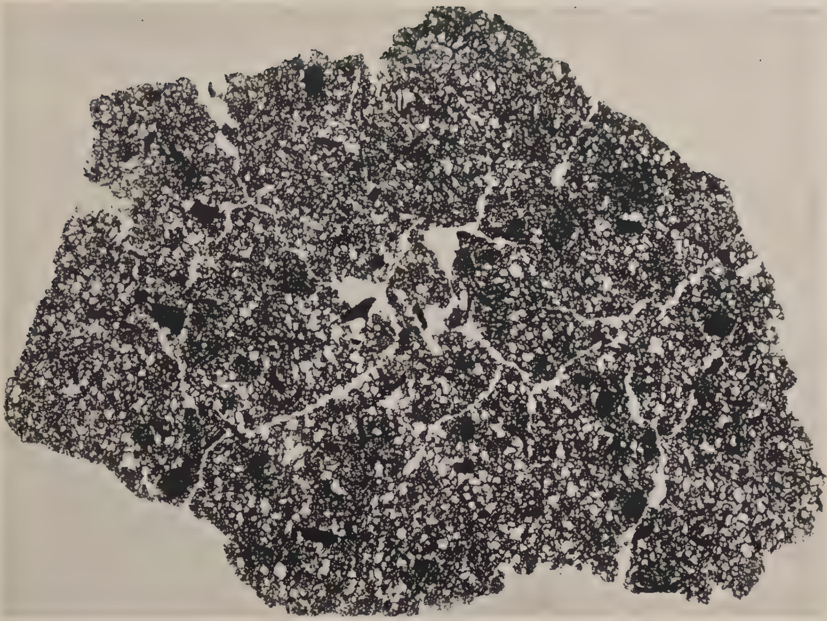


FIG. 2.—Longitudinal Fractures in Coke (Derbyshire, No. 15).

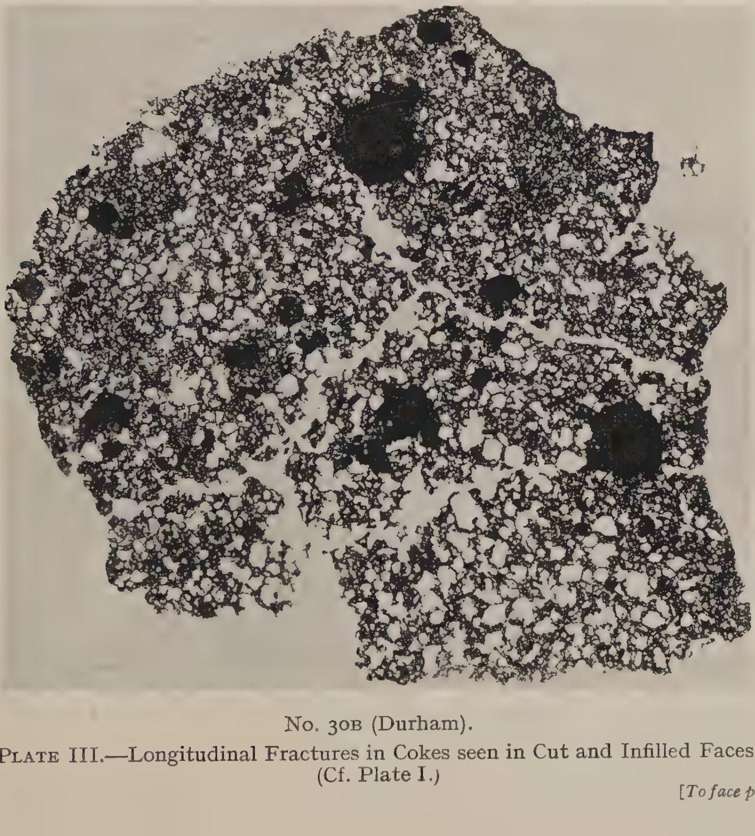
Cell-walls and Pores. The ultimate structure of coke is cellular, a network of cell-walls of varying thickness surrounding so-called " pores " of varying size. Some of the pores are closed, the cell-walls surrounding them completely, but the walls of the majority are partly broken. Such pores are usually referred to as " open." In some cokes the cell-walls themselves contain minute pores (" micro-pores ").

The pore structure (thickness of cell-walls and size of pores) of a coke does not affect its hardness considerably, as does the degree of fissuring, but appears to be of importance as regards its combustibility. The pore structure can readily be studied by examining, at low magnifications, preparations made by Rose's method, when the thickness of the cell-walls and the diameter of the pores can be measured. The percentage amount of total pore space can be determined from the apparent and real specific gravities of the coke, and the percentage of " open " pores by a modification of the usual method of determining apparent specific gravity.

Chemical Analysis.—The determinations commonly made by chemical analysis are for moisture, ash, volatile matter and sulphur.



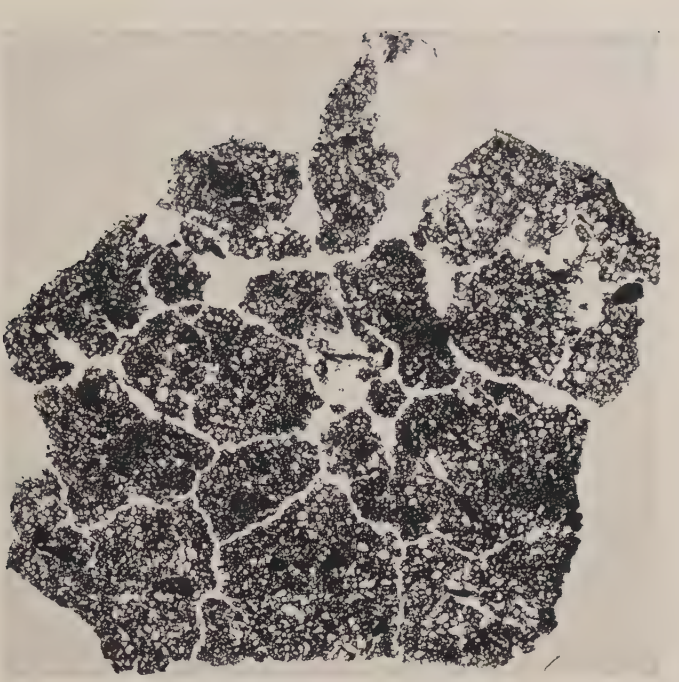
No. 43 (S. Wales).



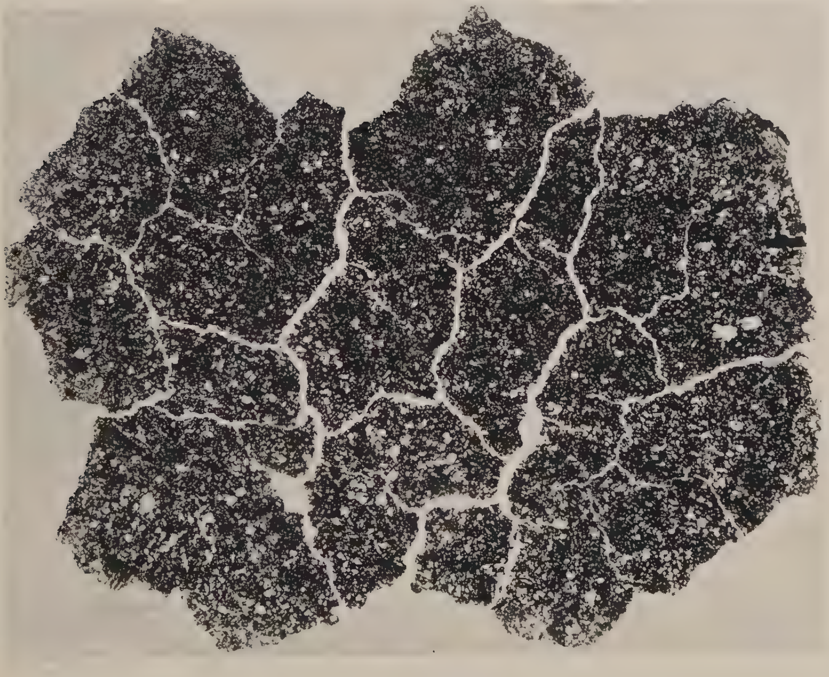
No. 30B (Durham).

PLATE III.—Longitudinal Fractures in Cokes seen in Cut and Infilled Faces. (Cf. Plate I.)

[*To face p.* 14.



No. 44 (South Yorkshire).



No. 45A (Derbyshire).

Plate IV.—Longitudinal Fractures in Cokes seen in Cut and Infilled Faces. (Cf. Plate II.)

[*To face p.* 14.

For cokes used in the manufacture of acid pig-iron the phosphorus-content is required; and when the coke is used for malt drying, it is necessary to know the arsenic-content. Determinations of nitrogen are not often made, and hydrogen and oxygen are rarely present in sufficient quantities to be of importance.

The carbon-content of a coke, being an index of its relative thermal value as a blast-furnace fuel, is its most important chemical property. It is not usual, however, to make direct determinations of carbon, but the sum of the moisture, volatile matter, ash and sulphur contents is subtracted from 100 to obtain the percentage of " carbon."

Real and Apparent Density and Porosity.—Knowledge of the real density of a coke (when calculated on an ash-free basis) is of interest as indicating the closeness of packing of the carbon molecules. We have found that this is related to the maximum temperature of combustion of the coke under standard conditions. In the past the principal use to which density determinations have been put has been to calculate the percentage porosity of the coke. The real density is measured from the weight of unit volume of the finely-ground material; the apparent density from the weight of unit volume of the unbroken coke.

Bulk-density.—The weight of a barrow-load of coke is affected not only by the apparent density of the coke, but also by the proportions of pieces of different sizes present. Small pieces in a load tend to fill the interstices between larger pieces, and a dense coke which is also brittle will provide the heaviest barrow-loads. The bulk-density of a coke affects the percentage of (coke) voids in the blast furnace. For given conditions of gasification at the tuyeres, a coke of low bulk-density (a high percentage of voids) provides a longer time of contact with the blast than does one of high bulk-density.

Abradability.—Measurements of the abradability, or abrasion hardness, of a coke are intended to give a measure of its liability to be broken or reduced in size by attrition during the settling of the burden in the shaft of the blast furnace.

A true abrasion test has been devised by A. Schmolke (*Gluckauf*, 1923, **59**, 3), in which a ground surface of coke, 2 in. square, is held with known pressure against a rotating emery wheel and determination made of the amount of powder rubbed off in a given time.

Several attempts have been made to devise suitable " tumbler " tests for the abradability or, as it is sometimes termed, the " hardness " of a coke (see, for example, Bell, *J. Iron and Steel Inst.*, 1904, **1**, 188; Cochrane, *ibid.*, 1918, **1**, 141; Hewson, *J. Soc. Chem. Ind.*, 1918, **37**, 60T; Rice, *Amer. Inst. Min. Met.Eng.*, 1922, **67**, 596; Perrott and Kinney, *J. Ind. Eng. Chem.*, 1922, **14**, 926). Cochrane, from nine years' experience with a tumbler test, came to the conclusion that " the practical success of the working of a blast furnace is chiefly dependent on the mechanical condition of the coke used" (*loc. cit.*, p. 141), an opinion supported by Rice. Perrott and Kinney found that the amount of breakage of a coke during their tumbler test depended on both abrasion and impact (shock). A coke which broke easily under "shatter test" (*q.v.*) gave a high "hardness" number under tumbler test, presumably because the larger the number of small pieces of coke formed the smaller was the production of breeze by crushing. It appears, therefore, that in tumbler tests both surface hardness (abrasion hardness) and impact hardness may operate simultaneously and affect the "index" obtained. It is doubtful whether in tumbler tests as ordinarily used a true measure of abrasion hardness has been obtained, but if the conditions of test are such that the effects of impact are minimised, and due allowance can be made for them, such a measure should be obtainable.

Impact Hardness.—The impact hardness of a coke is its ability to resist breakage. The stresses to which coke is subjected during transport in a wagon, and in the shaft of a blast furnace, are shearing stresses tending to abrade its surfaces. The more important stresses imposed on coke occur on its discharge from the oven on to the bench or coke-car, on loading it into wagons, on unloading it into hoppers and on dropping it to the charge-level of the blast furnace. These are all stresses due to impact. Their effects may be considerable and may differ in magnitude for different cokes.

Most of the breakage of coke in practice is due to impact. It is therefore convenient to reserve the term "hardness" of coke for its impact hardness, and to describe as "abrasion hardness" the surface hardness previously considered and sometimes referred to simply as "hardness." This restricted use of the term "hardness" is in conformity with the definition "resistance to fracture" suggested by Hadfield (*Proc. Inst. Mech. Eng.*, 1916, 710) for brittle materials, in contradistinction to "resistance to deformation" for ductile materials.

In impact tests used for determining the hardness of constructional materials, known loads are dropped from a given height on to a test-piece, and the energy required to break the test-piece is measured. An impact test of the same nature could be applied to coke, and has, in fact, been used in Japan, but the method employed by the United States Bureau of Mines, and adopted in America as standard, is preferable. In this so-called "shatter test" the amount of breakage caused when the coke "test-pieces" are dropped from a given height is measured. This method of testing conforms with the principles which the Hardness Tests Research Committee of the Institute of Mechanical Engineers considered should govern the determination of hardness: "In all cases . . . the practical method of solution is an experimental one, and consists in setting up a similar, or nearly similar, state of stress in a specimen of the material whose behaviour is under investigation and noting its effects" (*Proc. Inst. Mech. Eng.*, 1916, 677).

In the coke shatter test a large number of coke pieces (over 2 in. in size and weighing 50 lb.) is used to counterbalance the lack of homogeneity of coke. The effect of the impact stresses thus reproduced is measured by determining the proportion of the coke still remaining on a 2-in. screen (or on 1½-in., 1-in. and ½-in. screens) after it has been dropped four times. This proportion is termed the " shatter index " or " index of hardness."

Reactivity.—The term " reactivity " as applied to coke in the blast furnace may relate either to its behaviour towards carbon dioxide in the shaft or near the tuyeres, or to its reactions with the oxygen of the blast at the tuyeres.

Bell (*Journ. I. and S. Inst.*, 1885, **1**, 57) considered that marked reactivity of a coke with carbon dioxide in the shaft of the furnace was undesirable, as leading to excessive " solution loss " of carbon. On the other hand, during the period of marked increase in output from blast furnaces in America that was so noticeable during the later years of the Great War, blast-furnace operators called for a " fast-driving " coke, meaning thereby one which had a rapid rate of burning at the tuyeres. Howland (*Amer. Inst. Min. Met. Eng.*, 1916, **111**, 627), from a study of the working results of twenty-six American blast furnaces, concluded that " the most desirable thing about a coke is that quality in the carbon which will allow of its being instantaneously burnt to carbon monoxide." A coke for which the conversion into carbon monoxide was a comparatively long process would, he thought, be less economical. Koppers (*Stahl u. Eisen*, 1921, **41**, 1173, 1254), from an examination of the series of blast-furnace results studied by Howland, advanced the suggestion that the cause of the wide variations in coke consumption in the different furnaces lay in differences in " combustibility " (rate of reaction with oxygen) of the cokes used.

These two investigators, Howland and Koppers, have thus introduced the conception that the most serviceable coke for blast furnaces is one of high reactivity both with oxygen and with carbon dioxide. A measure of reactivity employed by Koppers, and by other investigators, has been the rate of reduction of carbon dioxide by a sample of the coke, broken into small pieces, at a temperature of 900–950° C. Other methods have been proposed and used. These will be described later in this Report.

In the succeeding chapters each of the qualities of coke concerned in its specification is considered in detail.

CHAPTER II

THE SIZE OF COKE

LIMITS of size of coke, both lower and upper, have from time to time been suggested as representing the useful limits in blast-furnace practice. The difficulty of determining with certainty, for such a large industrial unit as a blast furnace, the influence of one particular factor on its performance has militated against any general acceptance of these limits. Indeed, it is probable that the size of coke as a factor influencing the performance of a blast furnace is itself dependent on other conditions of operation of the furnace. Nevertheless, it is probable that many blast-furnace operators would welcome cokes of uniform size, say between 1½- and 3-inch mesh.

Consignments of two Westphalian cokes used with advantage in this country in both blast furnaces and cupolas during the coal stoppage of 1926 contained 88·8 and 82·2 per cent. between 1½- and 3-inch sizes, and only about 3 per cent. of less than 1-in. size.* At one blast-furnace plant in Germany the coke is crushed to produce a maximum of 2⅜-in. size, and all pieces of less than 1½-in. size are screened out. The success attending the use of coke graded in this way has induced other operators to adopt the practice (*Journ. I. and S. Inst.*, 1929, **119**, 50). In America it is customary to crush the larger coke (over 4-in.), and the rapid-coking ovens commonly used tend to produce a smaller coke than that usual in this country. At the Aliquippa works of Messrs. Jones and Laughlin, where the furnaces have the high output of 500–600 tons of pig-iron per day, the blast-pressure being 30 lb. per sq. in., the size of the coke used is approximately 2½- to 3-in. cube, all pieces below 1¼ in. being screened out. At Bethlehem steel works a similar size of coke is used. At another American plant the size analysis of a crushed coke, used satisfactorily, is: 59·7 per cent. over 1½ in. (of which only 17·9 per cent. is over 2 in.) and 12·5 per cent. less than 1 in.

Large coke offers less surface for reaction than the same weight of small coke, and the greater the variation in size of the coke pieces the less uniform is the descent of the stock. On *a priori* grounds one would be inclined to say that the only advantage to be gained by using coke of large size in a blast furnace would be a smaller "solution" loss in the shaft. The opinion of recent investigators.

---

* Both these cokes were made in rapid-coking narrow ovens (14-in.). A comparable result (76·5 per cent. between 1½- and 3-in. sizes) has been obtained in this country from a suitable blend coked in 14-in. ovens, but all coking coals do not give such a result in ovens of this width.

however, is that the amount of carbon not consumed at the tuyeres is about the same with all cokes (E. C. Evans and F. J. Bailey, *Journ. I. and S. Inst.*, 1928, **117**, 90). Clements (*Blast Furnace Practice*, Vol. I, p. 146. London, 1929) has pointed out that the gases traverse the distance between the tuyeres and the stock line in less than a second. Their composition can therefore be affected only by reactions of high velocity. The possible effect of the size of the coke pieces on the rate of removal of oxygen from the blast, or on the rate of transformation of carbon dioxide into carbon monoxide, by reason of the surface area they expose to the gases, can be gauged from Table II, which records the (external) surface area of cubes of coke of different dimensions.

TABLE II.—SURFACE AREA OF COKE PIECES OF DIFFERENT SIZES

Size of Cube (in.).	Surface Area (sq. in.).	Surface Area per lb. of Coke (sq. in.).
6	216	308
5	150	366
4	96	459
3	54	616
1½	13·5	1228
¾	3·4	2470
⅜	0·85	4930

From these figures it is apparent that 1 lb. of ¾-in. coke has as great an (external) surface area as 8 lb. of 6-in. coke. The amount of small coke in a consignment is therefore more likely to affect its "reactivity" than is the amount of large. So far as it is possible to estimate its value in a blast furnace, large coke, over 4 in., appears to have none. It is probable that the liking of blast-furnace operators for a large-sized coke has arisen, not from its intrinsic worth, but from the index it affords of the presence of but little breeze in the consignment.

A lower limit of size for coke to be of value in the blast furnace is universally admitted. It is a matter of economic importance to decide what the lower limit should be. At one blast-furnace plant coke pieces less than 1¼ in. were screened out between the hoppers and the skips. It was found that the output of the furnaces was greater, whilst the gross amount of coke used per ton of pig did not increase. In other words, the coke screened out (and used for other purposes) performed no useful function in the furnace, but reduced its output. The records (*vide* E. C. Evans, *Fuel*, 1927, **6**, 245) are given in Table III.

Coke pieces below a certain size fill the voids between the larger pieces and resist the passage of the blast, so that the increased surface due to the smaller coke pieces is counterbalanced by a reduced time of contact with the blast, less coke is burnt and less iron is melted.

In the present state of our knowledge it may be assumed that

TABLE III.—THE EFFECT OF REMOVING $1\frac{1}{4}$-IN. COKE IN BLAST-FURNACE PRACTICE

Period.	Coke arriving at Works (cwt. per ton of pig).	Coke Charged (cwt. per ton of pig).	Breeze (through $1\frac{1}{4}$) Screened Out (cwt.).	Total Burden (cwt.).	Average Make (tons per week).	Maximum Make (tons per week).
1921 . .	31·8	31·8	Nil	75·6	1150	1202
1925, three months . .	31·2	29·3	1·9	75·7	1380	1465

the minimum useful size of coke in a blast furnace lies between 1 and $1\frac{1}{2}$ in.

The size of coke when it arrives at the tuyeres of a blast furnace is governed by a number of factors, some operative at the coke-ovens and others after the coke has been discharged from the ovens. For example, the size of a coke is affected by the quality and size of the coal, or blend of coals, used; by the method of charging the oven and by the oven width (or the rate of penetration of heat through the charge); by its treatment during discharging, loading and unloading; and by attrition during its passage down the shaft of the blast furnace. To these factors affecting the size of most cokes must be added several others of occasional importance, such as roughness of the oven walls, lack of uniformity of heating of the oven and lack of uniformity of moisture content of the charge, which affect the ease of discharge of the coke from the oven and, in consequence, the amount of breakage during discharge.

It is convenient to consider each of the major factors in turn according as they relate to (1) the coal, (2) the oven, (3) the treatment of the coke between the oven and the blast furnace and (4) the blast furnace.

THE EFFECT OF THE COAL CHARGE ON THE SIZE OF COKE

Coking Quality.—The effect that the coking quality of the coal used has on the size of the coke produced from it is exemplified by the records of size analyses of commercial cokes given in Table IV. Each pair of cokes referred to in this table was produced under as nearly as possible identical conditions, the quality of the coal used alone being varied. It should here be noted that the size analyses of all samples of coke received at the laboratories, complete records of which are given in the Appendix to this Report, may not be directly comparable because the treatment to which the samples were subjected during transport to the laboratories has not always been the same. The pairs of cokes now under consideration, however, were accorded the same treatment throughout.

On comparing the sizes of the first pair of cokes (Nos. 17K and 17E), it will be seen that a higher proportion of large pieces was given by the coal with the higher caking index.* For the second pair

---

* For the distinction drawn between "coking" and "caking," see p. 168.

Table IV.—The Effect of the Coking Quality of the Coal on the Size of the Coke

Coke No.	Coal Used.	Caking Index (Campredon-Gray).	Laboratory Coking Test.*		Size Analysis of Coke.				
			Contraction (per cent.).	Expansion (per cent.).	On 4-in.	On 3-in.	On 2-in.	On $1\frac{1}{2}$-in.	On 1-in.
17K	Parkgate (S. Yorks.)	18	14	200	68·9	87·0	95·0	97·0	98·4
17E	Swallow Wood (S. Yorks.)	10	13	77	46·0	66·4	82·4	87·8	94·3
17D	Barnsley Hards (S. Yorks.)	8	28	Nil	82·9	88·2	93·0	94·5	95·8
17H	Barnsley Brights (S. Yorks.)	12	8	80	56·5	77·8	90·6	94·2	97·0
28C	Deep Hard (Derby.)	11·5	26	Nil	77·8	86·4	91·1	93·1	95·5
28B	Tupton (Derby.)	8	14	2	14·5	37·5	85·3	91·9	96·5

* *See* "Assessing the Value of Coking Coals," by G. W. J. Bradley and R. A. Mott, *Trans. Inst. Min. Eng.*, 1929, **76**, 200.

(Nos. 17D and 17H) the "hards" (mainly durain) and the "brights" (mainly clarain) from the Barnsley seam were coked separately. The hards yielded an abnormally blocky coke, mostly over 6 in. in size, which was rather more friable than the coke from the brights, so that it produced rather more breeze. In the laboratory coking test the Barnsley hards showed an abnormally large percentage contraction and no expansion. It would appear that the continued contraction of this coal during the plastic state ensured that subsequent loss of volatile matter did not cause as many shrinkage cracks as in the coke made from the Barnsley Brights. For the third pair of cokes (Nos. 28C and 28B) the conditions were nearly the same as for the second pair. The Deep Hard coal is a bright coal (mainly clarain).

Size of Coal.—The effect on the size of the coke of varying the size of the coal charged to the ovens has been determined by full-scale coking tests.

A number of wagon-loads of nuts, from a mixture of two similar seams, were crushed in a Sturtevant crusher and hand-screened to yield sizes represented approximately by the ranges 1 to $\frac{1}{2}$ in., $\frac{1}{2}$ to $\frac{3}{8}$ in., $\frac{3}{8}$ to $\frac{1}{4}$ in., $\frac{1}{4}$ to $\frac{1}{8}$ in., and $\frac{1}{8}$ to $\frac{1}{16}$ in. Through sizes with maxima of $\frac{1}{8}$ and $\frac{1}{16}$ in. were also prepared.

Each size of coal was top-charged to a regenerative oven of

20 in. mean width and heated during 30 hours. The resultant coke was sampled by collecting, at one end of the coke-car, a complete vertical section of the charge from 2 to 3 ft. in length after the front end had been pushed out. This sample was quenched, passed over a 1¼-in. bar screen and loaded into a wagon. It thus received normal treatment. Size analyses of the cokes are recorded in Table V, from which it will be seen that as the size of the coal charged decreased, the percentage of large coke produced, except as regards over 3-in. size, increased. The percentage of breeze (less than 1 in.) was high for the cokes made from the larger size of coal and decreased as the size of the coal used decreased.

TABLE V.—THE EFFECT OF THE SIZE OF COAL CHARGED ON THE SIZE OF COKE PRODUCED

Coke No.	Size of Coal Charged.	Size Analysis of Coke.			
		On 3-in.	On 2-in.	On 1½-in.	On 1-in.
3E (I)	1 to ½-in.	12·9	40·0	63·5	84·1
3E (II)	½ to ⅜-in.	26·4	51·2	68·9	85·9
3E (III)	⅜ to ¼-in.	27·9	58·6	75·1	89·9
3E (IV)	¼ to ⅛-in.	28·8	68·5	83·4	93·5
3E (V)	⅛ to $\frac{1}{16}$-in.	20·0	67·4	86·2	96·6
3E (VIII)	Through ⅛-in.	39·9	77·9	88·5	95·4
3E (VI)	,, $\frac{1}{16}$-in.	17·8	69·7	89·9	97·0

The results of shatter tests on these cokes are recorded graphically in Fig. 3. In these shatter tests, 50-lb. charges of pieces of size 2 to 3 in. and over 3 in. were mixed in the proportions shown by the size analyses and dropped four times from a height of 6 ft., to represent the treatment the coke would receive, after having been discharged from the oven, by the time it reached the charge level of the blast furnace. Fig. 3 records the percentages of sizes remaining on different screens after this treatment. It will be seen that the general strength of the coke increased rapidly as soon as coal of less size than ⅜-in. was used. The difference between the cokes made from ⅛ to $\frac{1}{16}$ in. and from through $\frac{1}{16}$ in. coal were not great, suggesting that, with this particular coal, the cost of very fine grinding would not be justified.

Blending the Coal Charge.—So far as the character of the coal charge is concerned, the factor most affecting the size of the coke produced is blending, either of coals or of coal and coke. For example, although a coal of low caking-power may produce a fingery (prismatic) coke, the admixture of a suitable proportion of another coal, of equally low or even lower caking-power, may improve the size of the coke. The blending with a coking coal of a small proportion of a non-coking material, such as anthracite duff or the breeze from low-temperature coke, improves the size of the coke whatever the quality of the coking coal used for the blend.

The use of a non-coking material for blending with the coal charge is, indeed, the most effective method of improving the size of coke, but regard must be paid to its effect on the hardness of the coke.

Perhaps the most interesting, because unexpectedly valuable, material to use is clean slurry. No doubt the slurry, because of the concentration of fusain in it, can itself be regarded as a blend of coking and non-coking materials. Full-scale tests on the coking alone of cleaned slurry from coking coals, whether good or poor, produced blocky cokes but little fractured, provided that the slurry did not contain too much fusain.

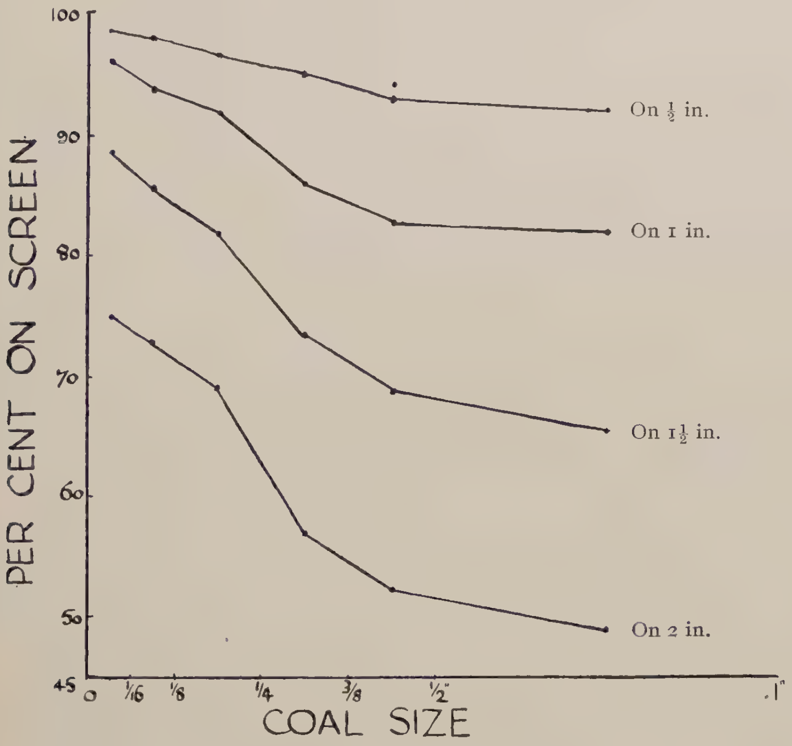


FIG. 3.—Shatter Test Results for Cokes made from Different Sizes of Coal.

Typical results of blending tests with different materials, as regards the size of the coke produced, are recorded in Table VI.

The effect of the fusain present in the slurry (coke No. 38A.s) is particularly noteworthy. The series of tests with a South Yorkshire coking slack ("box" tests, not full-scale oven tests) show the effects of a "fusain substitute," prepared by finely grinding breeze from low-temperature coke (coke No. 29Q(*b*)I(ii)), and of a natural dust rich in fusain (coke No. 29S (*b*) ii). Further details regarding these tests are given later in this Report.

TABLE VI.—THE EFFECT OF BLENDING THE COAL CHARGE ON THE SIZE OF THE COKE

District.	Derbyshire.			West Yorkshire.		South Yorkshire.		
Coke No.	22D.	22B.	22G.	38A.	38A.s.	29B (*b*).	29Q (*b*) I (ii).	29S (*b*) ii.
Coal Charge.	Deep Soft Seam alone.	With 30 per cent. Barnsley Seam.	With 20 per cent. Breeze from low-temp. Coke.	Coking Slack (half Beeston, half Silkstone).	Slurry from same Coking Slack.	Coking Slack (two-thirds Parkgate, one-third Silkstone).	With 2½ per cent. Breeze from low-temp. Coke (through 200-mesh).	With 5 per cent. Dust (through 1/16 in.) from Barnsley Coal.
Size analysis of coke :—								
On 4-in. %	2·7	19·2	66·3	15·2	36·3	15·8	56·5	56·9
On 3-in. %	16·1	50·9	79·5	30·7	76·3	38·2	65·6	68·8
On 2-in. %	56·7	79·8	85·3	58·1	90·4	78·5	79·4	81·0
On 1½-in. %	88·5	92·4	88·9	69·9	95·5	85·9	86·9	85·7
On 1-in. %	97·5	97·7	92·7	83·9	96·3	92·8	94·0	92·5

THE EFFECT OF OVEN CONDITIONS ON THE SIZE OF COKE

The Method of Charging.—A "top-charged" coke is usually more blocky than a "cake-charged" coke made, under otherwise similar conditions, from the same coal, and therefore usually contains a higher proportion of pieces of large size. The results of parallel tests recorded in Table VII illustrate this.

TABLE VII.—THE EFFECT OF THE METHOD OF CHARGING THE OVEN ON THE SIZE OF THE COKE

Coal Used.	Parkgate 67% Silkstone 33%		Parkgate 53% Silkstone 27% Barnsley 20%		Thorncliffe 59% Flockton 41%		Six-Quarter 75% Main Band 25%	
Coke No. Method of Charging.	29B. Top.	29A. Cake.	17A. Top.	17B. Cake.	18E. Top.	18C. Cake.	21A. Top.	21B. Cake.
Size analysis :—								
On 4-in. % .	13·7	14·6	59·8	41·8	43·8	28·6	19·7	13·1
On 3-in. % .	42·0	35·4	79·7	64·7	75·2	51·6	48·2	39·7
On 2-in. % .	78·5	75·1	90·9	83·3	92·9	81·3	73·6	67·3
On 1½-in. % .	89·0	85·9	94·6	91·5	96·0	92·6	87·1	85·1
On 1-in. % .	95·2	94·6	97·1	97·2	98·0	97·5	94·0	94·5

The Rate of Heating.—In earlier coke-oven practice the width of the ovens did not vary much from a mean of 20 to 21 in. and the flue temperatures did not usually exceed 1150° C., the use of semi-silica brick imposing a limit of temperature. In modern practice the ovens are narrower and are usually built of silica brick, flue temperatures of 1400° C. or more being employed.

The coking-times of ovens of different widths, with a given flue temperature, are roughly proportional to the squares of the widths. For an oven of given width the coking-time decreases with rise in temperature of the flues. The effect of decreasing the coking-time is to increase the rate at which the coal charge passes through the plastic state. It also increases the rate of evolution of volatile matter after the coke-structure has become rigid, most of the volatile matter being expelled at this stage of the coking process. The result of this rapid evolution of volatile matter is pronounced shrinkage stresses and, in consequence, small coke. The flue temperature does not directly affect the size of the coke, except in so far as it increases the rate of heating, because, owing to the rapid heat transference, the temperature of the oven walls of modern narrow ovens of silica brick is often as low as that of the older ovens. If the coke remains in the oven for even a short time after coking is complete, however, the wall temperature rises rapidly and the adjacent coke undergoes further shrinkage and a further reduction in size.

Size analyses of a number of cokes made, with different rates of heating, from high-volatile Yorkshire coals top-charged to the ovens, are recorded in Table VIII.

TABLE VIII.—THE EFFECT OF THE RATE OF HEATING ON THE SIZE OF THE COKE

Coal Used.	Thorncliffe 59% Flockton 41%			Parkgate 67% Silkstone 33%		Wath Wood Haigh Moor		Parkgate and Silkstone 80% Wath Wood & Haigh Moor 20%	
Coke No.	18E.	18F.	18A.	29B.	29C.	29D.	29E.	29F.	29G.
Width of Oven (in.)	20	19	14	21	14	21	14	21	14
Coking Time (hr.)	32½	19¼	12	22½	12	22½	13	24	12¼
Size analysis :—									
On 4-in.% . .	43·8	3·1	31·6	13·7	6·5	14·4	3·2	17·7	1·3
On 3-in.% . .	75·2	23·2	56·5	42·0	31·9	36·6	18·5	38·4	11·9
On 2-in.% . .	92·9	63·8	82·1	78·5	82·2	71·1	62·4	71·8	58·1
On 1½-in.% . .	96·0	83·4	91·3	89·0	93·5	84·0	80·3	85·0	81·2
On 1-in.% . .	98·1	94·4	96·2	95·2	97·3	93·4	91·7	94·4	93·1

It will be seen from these results that, in general, an increase in the rate of heating the coal charge causes a decrease in the size of the coke. An exception is provided by coke No. 18F, coked in 19¼ hours in a 19-in. oven, which was smaller than the coke made, from the same coal, in a 14-in. oven, with a coking-time of 12 hours (coke No. 18A). It may be that the heating of coke No. 18F was carried beyond the coking-time.

THE EFFECT OF MECHANICAL TREATMENT AFTER MANUFACTURE ON THE SIZE OF COKE

It is well known that a coke as discharged from the oven is more massive than when it is charged to the blast furnaces. This reduction in size is due almost entirely to the mechanical treatment the coke perforce receives during its transference from ovens to the furnaces. The effect on its size of dropping coke from different heights is well shown by a comparison of the pieces visible at the top of a wagon on arrival at a blast-furnace plant with those disclosed when the side door of the wagon is dropped (cf. Figs. 4 and 5).

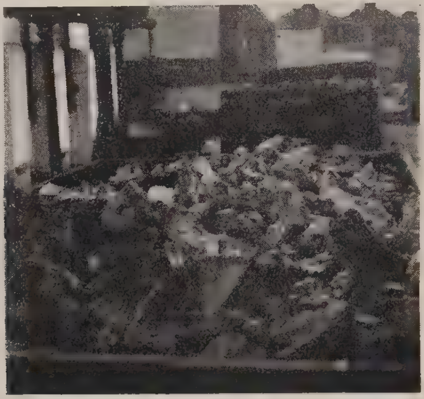


FIG. 4.—View of Coke on Top of a Wagon on Arrival at a Blast-furnace Plant.

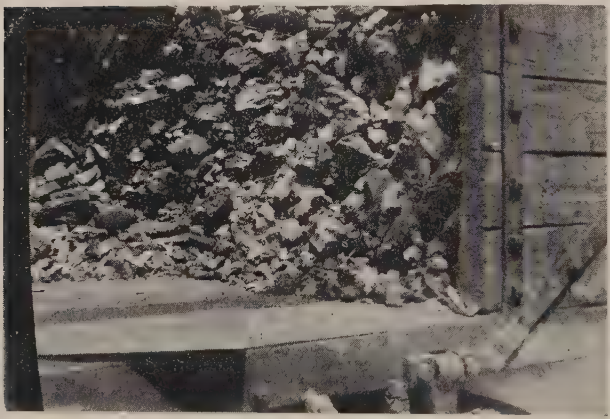


FIG. 5.—View of Same Wagon of Coke Through the Side Door.

The coke at the top of the wagon had been dropped about 2 ft. only, and was of nearly the same size as when on the coke-oven bench. The coke seen through the wagon door was partly broken up, that at the bottom (which had been dropped about 7½ ft.) being the smallest. Size analyses were made on a number of wagons of this coke, on its arrival at the blast-furnace plant, by making a vertical cut through the contents of the wagons and screening the samples so obtained. The average of samples taken several times daily over a period of a fortnight showed 11·7 per cent. of breeze (through 1½-in.).

The breeze produced at different stages of handling coke between the ovens and the furnaces has been estimated by loading at a coke-oven plant the contents of several ovens separately into wagons after shaking the coke on forks having prongs 1¼ in. apart, the undersize (breeze) being collected. The coke-oven plant at which these tests were made had a flat bench, so that the breeze produced up to the point of loading into wagons was not caused by breakage due to dropping, but by such causes as the impact of the ram head and the resistance offered by rough portions of the oven walls to the discharge of the coke. After loading into wagons, the coke was screened and all pieces that would pass through a 1½-in. screen, in any position, were collected and weighed. The results of these tests are recorded in Table IX.

TABLE IX.—BREEZE FORMATION AT OVENS AND ON LOADING (Coke No. 17JL)

Oven No.	11.	12.	18.	21.	32.	35.
Breeze (1¼-in.) at oven :—						
Per cent. on total coke	6·4	10·7	4·9	5·5	7·3	6·0
Per cent. on coke loaded	6·9	12·0	5·1	5·8	7·9	6·4
Average for all ovens	7·4					
Breeze (1½-in.) after loading :—						
Per cent. on coke loaded	8·1	8·8	6·6	7·6	7·2	8·1
Average for all ovens	7·6					

It will be noted that the amount of breeze formed at oven No. 12 was nearly twice as much as at the other ovens. This was due to the fact that oven No. 12 was in a bad state of repair and was unevenly heated.

The results show that by dropping the screened coke into wagons, about 7½ per cent. of breeze was formed, or as much as was produced at the ovens and collected on the bench.

Further tests on the breakage of coke at the ovens were made at eight ovens using screening forks with prongs 1⅛ in. apart, these being the forks employed in practice for loading the coke into the wagons.* These tests showed that the amount of breeze screened out averaged 6·4 per cent., or 1 per cent. less than in the previous tests, where forks with 1¼-in. prongs were used. Normally, therefore, the coke in the wagons leaving the ovens would contain about

---

* The use of forks with 1¼-in. prongs in the earlier tests was dictated by local conditions. If 1½-in. prongs had been used, no doubt the figure for the amount of breeze screened out on the bench would have been increased and that for the amount of breeze formed on loading would have been decreased correspondingly. This would not, however, affect the figure obtained for the average amount of 1½-in. breeze in the coke leaving the plant under normal conditions.

8½ per cent. of breeze. On comparing this figure with determinations made at the blast-furnace plant, it was found that about 3 per cent. more breeze (through 1½ in.) had been formed during the transport and shunting of the wagons over a journey of about 40 miles.

The amount of coke breeze thus formed, on dropping into wagons and during transport, naturally varies with the quality of the coke. Table X records the results of size analyses of a number of Yorkshire cokes on delivery at the same (Lincolnshire) blast-furnace plant. The results show that, of eight Yorkshire cokes, one contained as much as 28 per cent. of breeze (through 1½-in.) and three contained more than 20 per cent.

TABLE X.—SIZE ANALYSES OF YORKSHIRE COKES AS DELIVERED AT A BLAST-FURNACE PLANT

Coke No.	Size Analysis.					Breeze (through 1½-in.), per cent.
	On 4-in.	On 3-in.	On 2-in.	On 1½-in.	On 1-in.	
M	17·7	26·0	57·0	71·9	85·9	28·1
33	9·1	26·3	59·4	77·0	89·3	23·0
29H	15·2	34·6	64·9	78·5	89·3	21·5
34	27·5	49·2	69·6	82·7	92·5	18·3
26C	29·9	51·0	72·3	82·8	91·8	17·2
35	19·9	44·2	68·9	83·2	93·3	16·8
32	27·9	52·1	75·5	86·0	93·5	14·0
17JL	30·5	55·7	78·2	88·3	95·0	11·7

The breeze found in coke on its arrival at the blast-furnace plant is mainly formed when it is dropped into the wagons. At the blast-furnace plant there is further dropping of the coke on unloading into hoppers and on discharge to the charge-level of the furnace. It is therefore important to determine the effect of dropping coke from different heights.

Samples of cokes, originally over 2 in. in size, were dropped from heights of 24, 12, 6 and 3 ft., as recorded in Table XI. The results show that the breakage is proportional to the total height through which the coke is dropped, whether the operation is carried out in one stage or in several.

Although the effects of one drop from a height and of a number of drops from a smaller height giving the same aggregate are about the same, the effects of each of a number of drops from the same height differ, the earlier drops causing the greater breakage. This is shown by tests with different cokes in which samples of over 2 in. size were dropped twelve times from a height of 6 ft., size analyses being made after each drop. The results for three representative cokes are recorded in Table XII and graphically in Fig. 6. From Table XII it will be seen that, dependent on the quality of the coke, a point is reached at which further dropping causes considerably less breakage. With a good Yorkshire coke (No. 17K), the

TABLE XI.—THE EFFECT OF DROPPING COKE FROM DIFFERENT HEIGHTS

Coke No.	Total Height Dropped (ft.).	Number of Drops and Height of Each (ft.).	Size Analysis.		
			On 2-in.	On 1½-in.	On 1-in.
1A	24	1 × 24	97·7	98·2	98·7
	24	2 × 12	95·7	98·1	98·7
	24	8 × 3	96·6	98·4	98·7
	36	3 × 12	94·2	97·7	98·3
	36	12 × 3	95·0	97·9	98·4
31A	24	1 × 24	87·8	93·8	97·3
	24	2 × 12	83·3	91·5	96·2
	24	4 × 6	81·0	91·7	96·6
17K	24	1 × 24	77·3	87·0	95·2
	24	4 × 6	75·8	87·6	95·3
3C	24	1 × 24	78·7	90·9	96·5
	24	2 × 12	78·3	88·2	94·5

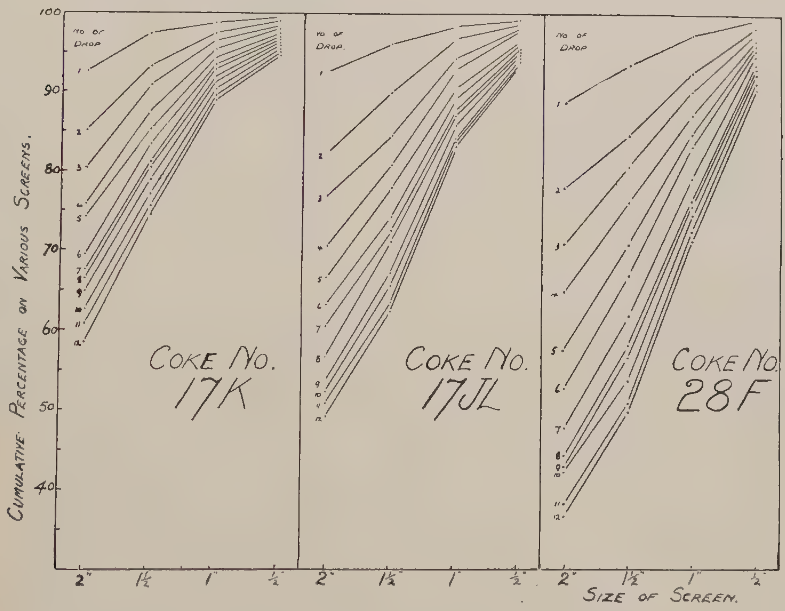


FIG. 6.—The Effect of Twelve Successive 6-ft. Drops on Three Cokes.

breakage is reduced after four drops; with a Yorkshire coke of medium quality (No. 17JL) six drops are necessary before the subsequent breakage is diminished; and with a Derbyshire coke (No. 28F) eight drops are required.

TABLE XII.—BREAKAGE OF COKE CAUSED BY SUCCESSIVE DROPS FROM A HEIGHT OF 6 FT.

Decrease in Amounts of on-2-in. and on-1½-in. Sizes (per cent.).

Drop No.	Coke No. 17K (S. Yorks.).		Coke No. 17JL (S. Yorks.).		Coke No. 28F (Derbyshire).	
	2-in.	1½-in.	2-in.	1½-in.	2-in.	1½-in.
1	7·4	2·7	7·6	3·8	11·3	6·7
2	7·5	4·1	10·2	6·3	10·9	8·9
3	4·8	2·4	5·3	5·5	7·0	4·0
4	4·5	3·2	6·2	3·6	5·9	4·3
5	1·6	2·3	4·1	3·0	7·6	5·4
6	4·8	1·9	3·4	3·6	4·9	4·0
7	1·7	2·2	2·8	1·8	4·9	5·0
8	1·1	0·8	3·7	1·3	3·5	3·7
9	1·7	1·6	3·3	3·9	1·3	1·4
10	2·3	1·8	1·3	1·8	0·5	3·1
11	1·7	1·5	1·3	1·9	4·3	2·8
12	2·4	1·0	1·8	1·2	1·6	1·0

These results are of interest in connexion with a view sometimes expressed that coke should be deliberately roughly handled at the ovens to produce as much breeze as possible, which should be screened out; but little more breeze would then be formed on further handling at the blast furnaces. The results in Table XII show that before the necessary stability of the coke had been reached the amount of breeze formed would be excessive. For example, with the Derbyshire coke (No. 28F) the amount of breeze formed before stability would be approached would be about 54 per cent., not taking into account that formed on the discharge of the coke from the ovens. Not only would the task of disposing of this amount of breeze, as domestic nuts, for example, be a formidable one, but the mechanical treatment of the coke necessary to produce it would be uneconomical.

It must therefore be assumed that each drop that coke undergoes during its normal treatment at the blast-furnace plant will result in the formation of breeze. The greater the aggregate height through which the coke is dropped, the more breeze will be formed. Since breeze is not desired by the blast-furnace operator, he should avoid handling and loading plant in which unnecessary dropping of the coke occurs.

THE EFFECT OF ATTRITION IN THE BLAST FURNACE ON THE SIZE OF COKE

The amount of breakage of coke that occurs within the blast furnace appears to have been over-estimated in the past. As has been shown, breakage occurs when the coke drops to the charge-level of the furnace, the amount depending on the distance dropped and the hardness of the coke. The impact of ore and limestone on to the coke at the charge level will also break it, but thereafter

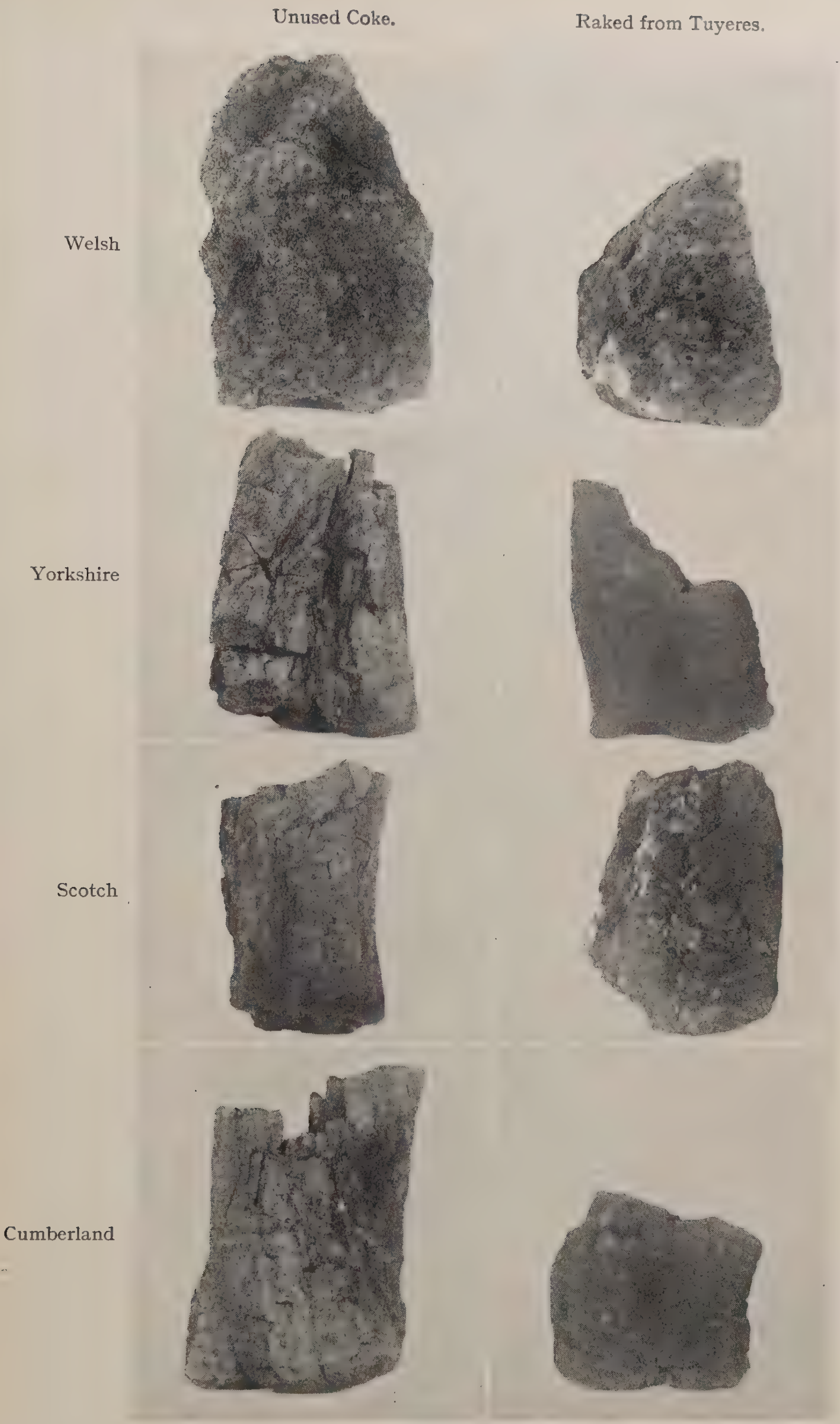

Unused Coke.
Raked from Tuyeres.
Welsh
Yorkshire
Scotch
Cumberland

Plate V.—Comparison of Coke Raked from Tuyeres of Blast Furnace with Unused Coke (Cf. Plate XXV.)

[*To face p.* 30.

there is no free fall of any part of the charge and the coke is subjected to no further impact stresses. It settles with the burden down the shaft, and, since this settling motion is least rapid at the centre line of the furnace, rolling occurs towards the lining until the almost stationary shell of material next to the lining is reached. The volume changes in the burden as it passes down the shaft are inconsiderable, and the movement of the coke relative to the rest of the material can be but small. Some rubbing of the edges of the coke pieces will occur as the burden settles, and uneven settling across the diameter of the furnace may sometimes cause local pressure.

The appearance of pieces of coke raked from the tuyeres of a number of blast furnaces, compared with that of unused coke pieces, is illustrated on Plate V. The edges are slightly rounded. This appearance has been reproduced by rotating coke in a smooth-walled cylinder nearly filled with it, so that the pieces rolled and slid over each other without dropping. The amounts of breakage of a number of different cokes subjected to this treatment are recorded in Table XIII.

TABLE XIII.—BREAKAGE OF COKES SUBJECTED TO ABRASION TEST

Coke No.	Size Analysis.				
	On 2-in.	On 1½-in.	On ½-in.	On 1/16-in.	Through 1/16-in.
1A (S. Wales)	88·9	94·8	95·8	96·4	3·6
2A (Durham)	83·3	97·0	98·5	99·0	1·0
7 (S. Yorkshire)	82·8	94·7	98·3	98·5	1·5
15 (Derbyshire)	84·5	90·4	96·2	96·6	3·4
16 (Lancashire)	74·9	92·6	97·8	98·5	1·5
20B (Cumberland)	74·7	91·4	97·1	97·8	2·2
24 (Kent)	63·0	93·5	96·2	96·7	3·3
36A (Sarre)	81·4	91·9	97·2	98·2	1·8

In this "abrasion test," 25 lb. of 2-in. to 3-in. coke are rotated during 30 minutes at 20 r.p.m. in a cylinder 18 in. in diameter and 9 in. long. The amount of coke used for the test occupies about 80 per cent. of the volume of the cylinder. During the 600 revolutions to which the coke is subjected the pieces roll over each other without dropping any distance. As already stated, the appearance of the coke pieces at the conclusion of the test is similar to that of coke withdrawn at the tuyeres of a blast furnace. The test therefore reproduces approximately the abrasion forces to which coke is subjected during its passage down the shaft of the furnace.

The results recorded in Table XIII show that, although a high proportion of the coke can pass through a 2-in. screen after the test, most of it remains on a 1½-in. screen, so that the actual reduction in size of the pieces is small. Most of the loss is dust, passing a $\frac{1}{16}$-in. screen.

In general it may be said that the breakage of coke by attrition in the shaft of a blast furnace is small and is occasioned mainly by the removal of fine particles from the edges of the pieces. This removal of dust is greatest with cokes made from coals of low caking-power (*e.g.* No. 15), or from a blend that contains non-coking material, such as No. 1, which was made from a blend of a coking coal and a steam coal.

CHAPTER III

THE STRUCTURE OF COKE

WHEN considering the structure of coke, it is convenient to distinguish between its macro-structure, visible to the unaided eye, and its micro-structure, the detailed structure of the cell-walls and pores, for the proper examination of which some degree of magnification is necessary.

MACRO-STRUCTURE

The macro-structure of coke may be held to include the shape and general external appearance of the coke pieces, and their internal fractures.

Shape.—The shape of the coke pieces is of importance because it affords a reliable guide as to the general quality of the coke, in particular as to its liability to form breeze during handling.

The by-product cokes of highest reputation as blast-furnace cokes—those made from South Wales and Durham coals—are nearly rectangular in longitudinal section and hexagonal in transverse section (see Plates VI to VIII).

In the poorest metallurgical cokes (*e.g.* those from Derbyshire coals), the shrinkage lines of the charge have not been at right angles to the oven walls, but inclined or, more frequently, curved. The longitudinal sections of the coke pieces are therefore either regular (straight) or irregular (curved) parallelepipeds (Plate X). The transverse sections are hexagonal but irregular, two of the sides being almost invariably elongated. The pieces are therefore narrower in one dimension (in the plane parallel to the oven wall) than in another. The curvature from the centre of the oven is invariably at one of the narrow ends. Since the curvature is always upwards from the oven sole, this means that, in the oven, the longer dimension of the hexagon is in a vertical plane at right angles to the oven sole and the axis of the oven. Since the pieces narrow towards the centre of the oven, the curved centre-of-oven ends are much weaker than the cauliflower ends at the oven wall and are easily broken off during handling. Examples of this type of coke are shown on Plate X.

A study of the causes of these observed differences in the shapes of coke pieces is desirable, to determine whether it is possible in practice to modify the character of the fissuring of the coke charge. Counterparts to this fissuring are to be found in the natural fissuring of igneous rocks and in the cracking of dried mud at the sides of a depleted reservoir, or of the surfaces of garden soil during drought. Similar phenomena have also been observed in the laboratory during experiments on the drying of starch paste.

In these examples, fissures are produced through the shrinkage of a plastic material during drying or solidification, and it is found that, in a uniform medium, the cracks tend to run along planes at angles of 120° to each other, forming hexagonal outlines. The hexagon, or its approximation, is the only geometrical space-filling form, other than the square, observed in Nature. The square, or its approximation, is observed in sedimentary rocks, such as sandstones or coals, where shrinkage occurs at right angles to the bedding planes, but when sedimentary deposits dry and harden on the earth's surface, they exhibit hexagonal shrinkage cracks. Fig. 7, for example, is a photograph of the surface of dried mud on the banks of the Birchenlee reservoir, Derbyshire.

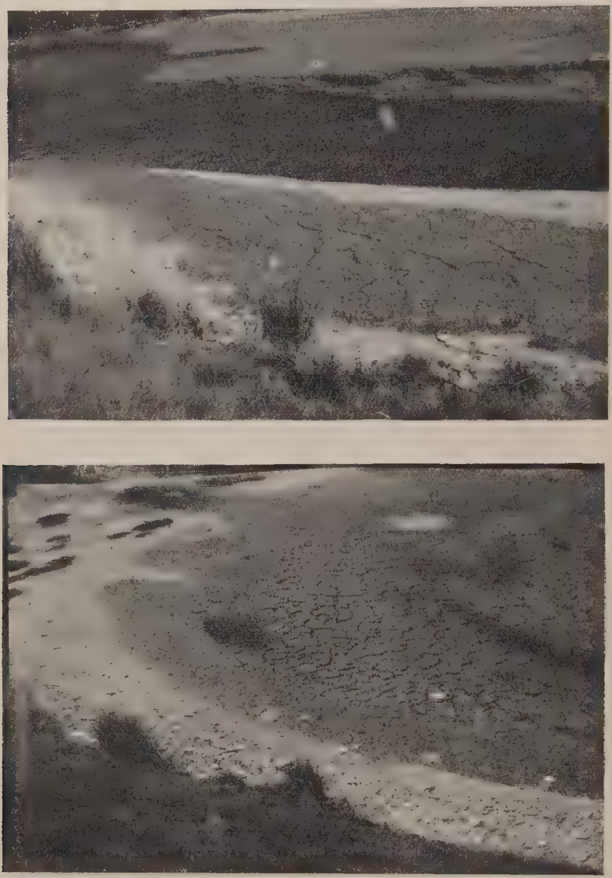


Fig. 7.—Shrinkage Cracks in Mud at Birchenlee Reservoir.

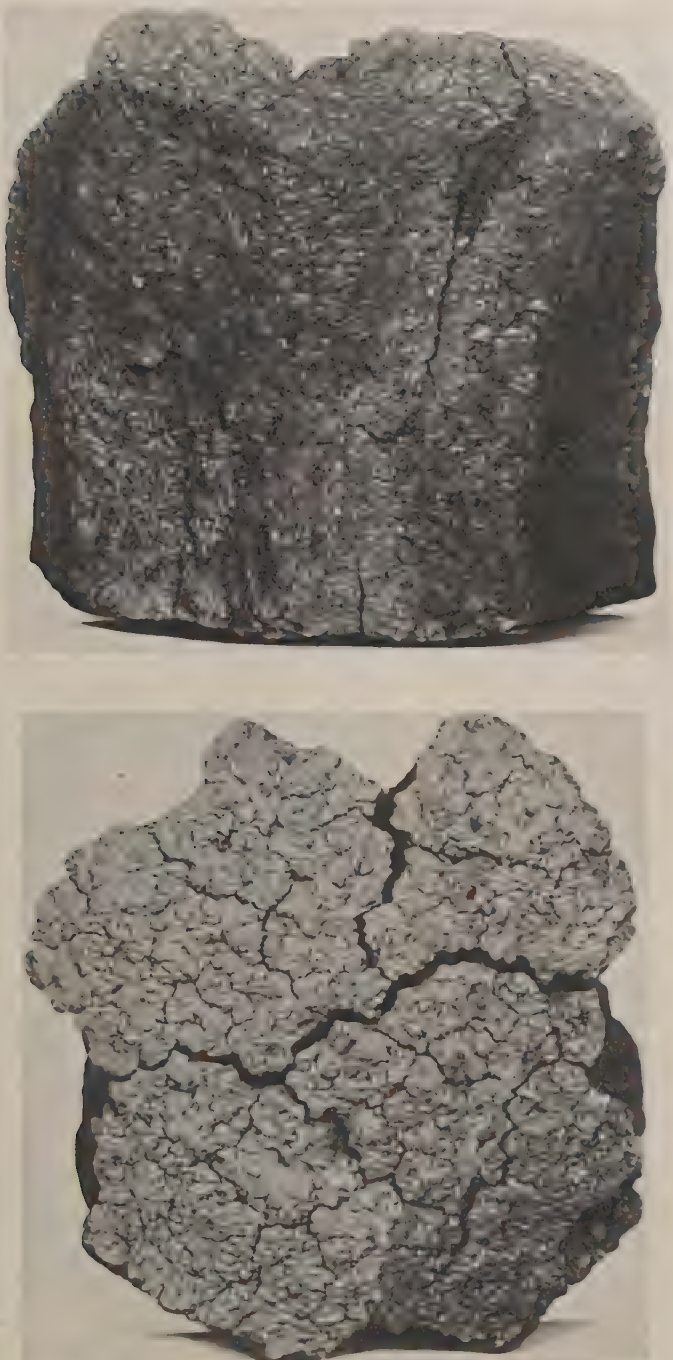
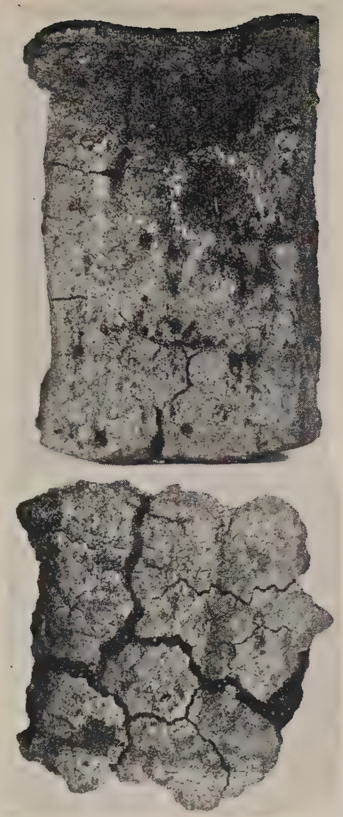
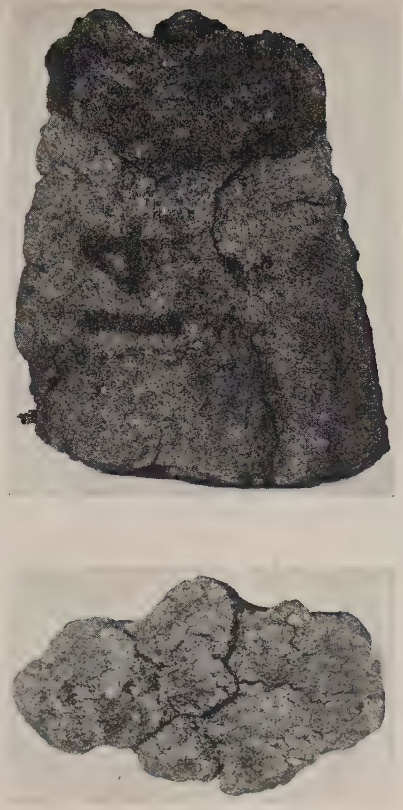


PLATE VI.—South Wales Coke (No. 1): Longitudinal and End Views.

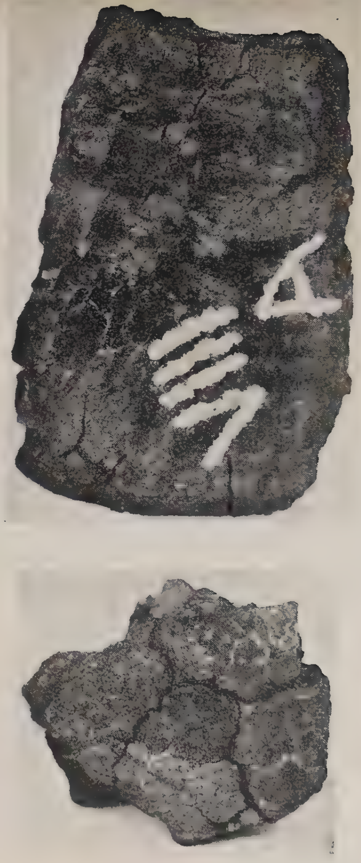
[*To face p.* 34.



No. 39.



14.



8a.

Plate VII.—South Wales Cokes: External Views.

[*To face p.* 34.

E

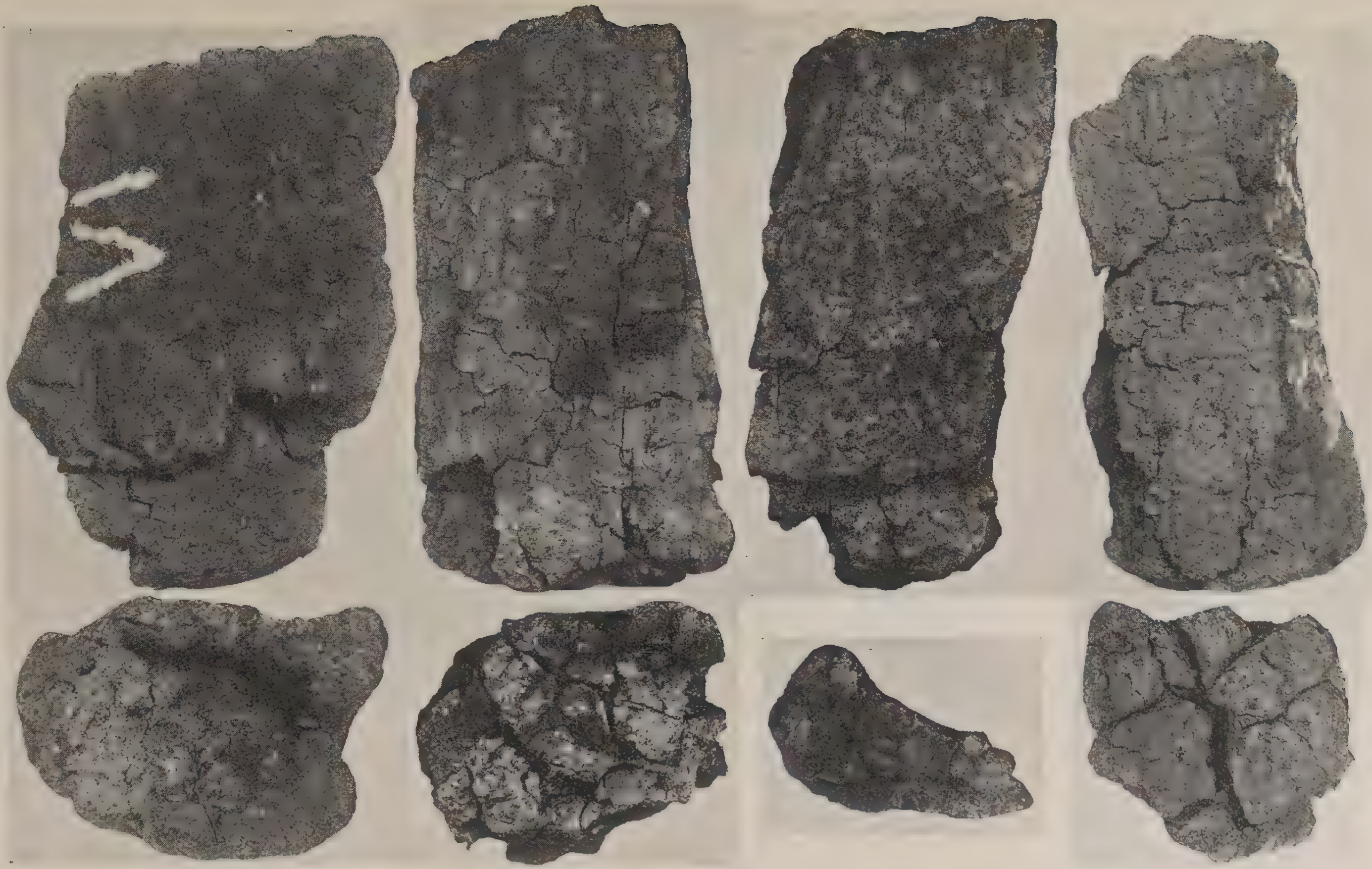

No. 6.
41.
30A
30B.

PLATE VIII.—Durham Cokes: External Views.

[*To face p.* 34.

Good examples of regular hexagonal structures in a cooled molten material, the shrinkage cracks having started from uniformly disposed nuclei, are to be found in the Giant's Causeway. In this formation, however, the six-sided figure, though most frequent, is not invariable. Sometimes, no doubt because circumstances have caused the formation of shrinkage cracks from irregularly disposed nuclei, five-sided structures have been produced, whilst the six-sided structures themselves are most often irregular. The fact that such irregularity occurs with a comparatively uniform igneous rock prepares us to find similar, or more pronounced, irregularity with coke.

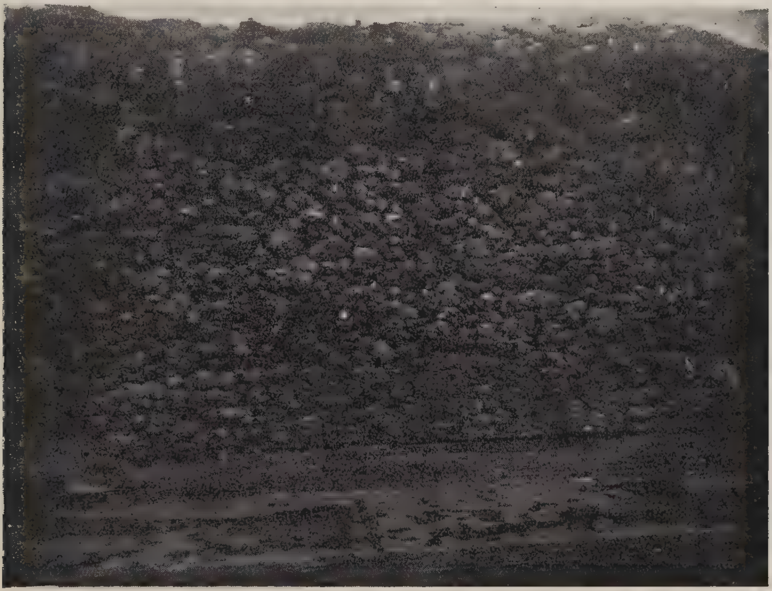


FIG. 8.—Shrinkage Cracks in Wall of Coke Pushed out on to a Flat Bench.

The photographs of "cauliflower ends" reproduced on Plates VI to X show that, whilst six-sided structures can always be recognised, they are sometimes indistinct and almost invariably irregular, the sides being of different lengths and often curved. Fig. 8, a photograph of a wall of coke pushed out of an oven on to a flat bench, well illustrates this. Five-sided structures, due to the absence of a sixth nucleus during shrinkage, can sometimes be observed (see coke No. 37, Plate IX.)

Shrinkage cracks in the coke charge cannot begin to form until the coal has passed through the plastic stage and become rigid. Foxwell (*Fuel*, 1924, **3**, 230) has shown that, on heating representative coking coals from South Wales, Durham and Yorkshire at a rate of 1° C. per minute, not much more than half their contents of volatile matter is evolved up to the time that a rigid "coke"

Derbyshire coals) it is low. With poor caking coals, therefore, the gases from the hot side of the plastic layer can more readily pass through and convey heat to the coal charge beyond, particularly near the oven sole, where the resistance of the alternative path for the gases (upwards through the coke column) is greatest.* With such coals the part of the charge near the oven sole is coked many hours before the upper part, and the isothermal lines in the ovens are of the type illustrated in Fig. 9. The ends of the coke pieces at the centre of the oven therefore tend to be curved.

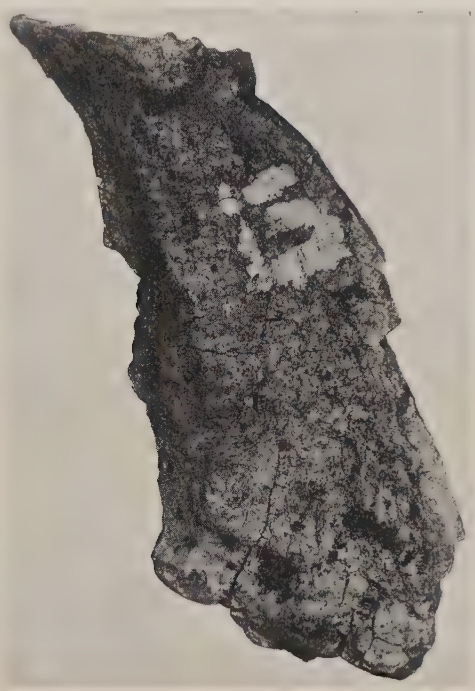


FIG. 10.—Curvature in South Wales Coke.

The effects due to the character of the isothermal lines in the oven can be modified. With South Wales cokes, for example, curved ends to the pieces are rarely seen, though one is illustrated in Fig. 10. Coke of foundry quality is commonly made (from poorly caking coals) in South Wales with slow rates of heating, often in non-recovery Coppée retort ovens or in waste-heat ovens with low flue temperatures. Blends with non-coking steam coals are frequently used, with the result that the cross-sectional dimensions (hexagonal) of the coke pieces are increased (see Plate VI). Some Welsh coking coals, also, are strongly swelling, and the resistance of the plastic layer to the passage of gas is comparable with that obtaining with Durham and Yorkshire coals. Moreover, the volatile matter content of the blends charged to the ovens is low (about 20 per cent.) and the loss of weight of the charge after the rigid coke structure has just formed rarely exceeds 10 or 12 per cent. The total amount of shrinkage is therefore small.

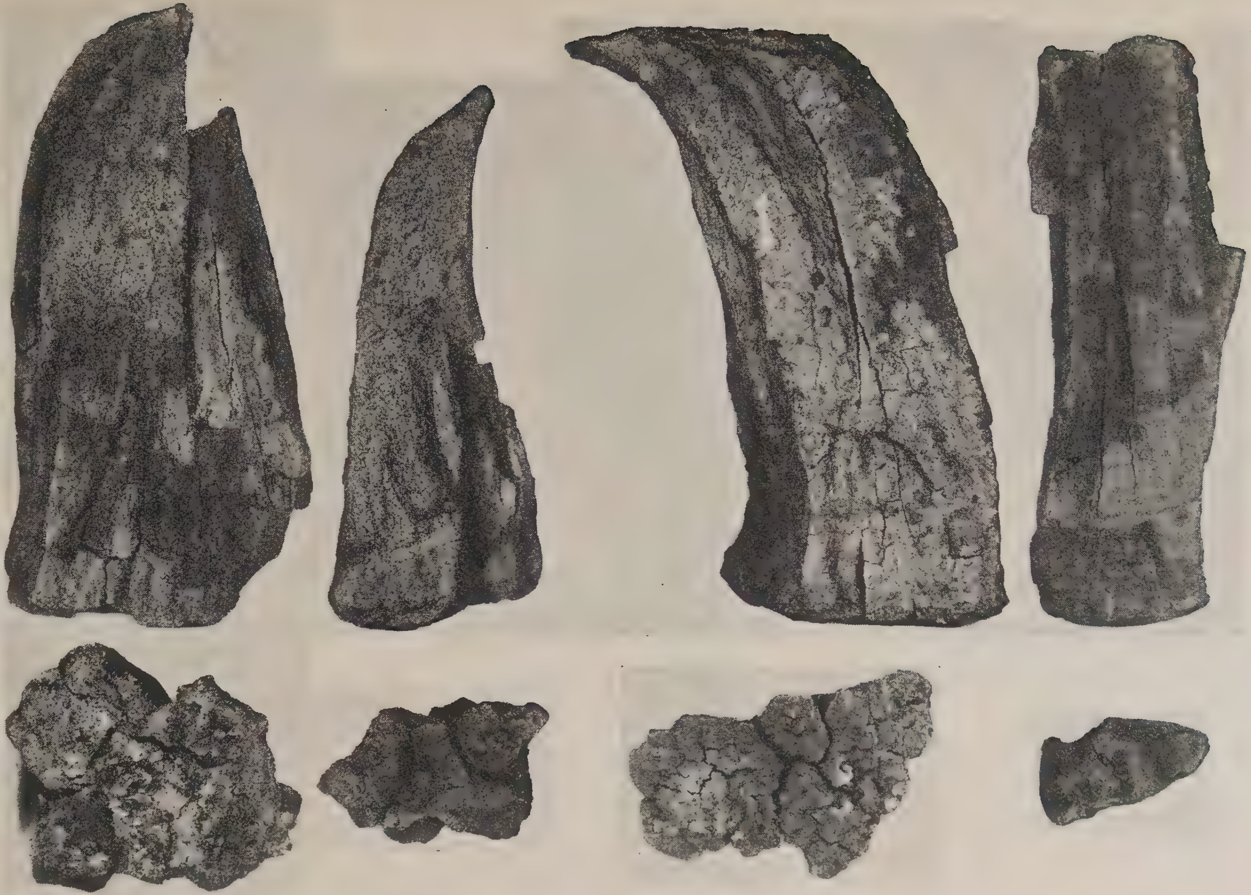
---

* The coking time, however, depends on the rate of carbonisation at the top of the oven. Although shorter coking times have been obtained with Welsh and Derbyshire coals as compared with, for example, Durham coals, the reduction has not been as great as is possible, owing to the practice of building the horizontal flue very low, to avoid over-heating of the free-space above the charge and thus to conserve the by-products. It has, in fact, been observed that, with a Westphalian low-volatile coal, the temperature of the charge at the oven sole in an old-type Koppers oven reached 900° C. near the centre 8 hours before the top of the charge in the same vertical plane had attained that temperature. (See *Fuel*, 1925, **4**, 316.)

With cokes made from Derbyshire and Staffordshire coals, or from the poorer Yorkshire coals, the curvature of the centre-of-oven ends of the pieces is always well marked. In Derbyshire, at one coke-oven plant, an attempt has been made to modify the character of the coke pieces by simulating the practice of South Wales of slow heating, 24-in. ovens being used with a coking time of 50 hours. The resultant coke, however, still showed characteristic curvature (see No. 15, Plate X), no doubt because the rate of heating of most of the charge was not slow enough, the coking of a 24-in. oven in 50 hours demanding as high a flue temperature as that of a 20-in. oven in 35 hours. The slow coking in South Wales, productive of a coke such as that on Plate VI, is obtained by the use of low flue temperatures, 18- to 20-in. ovens being coked in about 48 hours.

The blends used for coking in Derbyshire are of coals of the same type, so that the shrinkage phenomena are those of a single caking coal. The coals are but slightly swelling, are usually of low caking index and contain 35 per cent. or more of volatile matter (on an ash-free, dry basis). Moreover, stamped charges are invariably used, so that, on coking, the loss of weight from unit volume of oven space is high. All these factors favour shrinkage, with the consequent formation of numerous fissures, and there is no modifying factor as with the Welsh cokes.

Another factor may influence the direction of the shrinkage cracks—namely, variation in the rate of heating of different portions of the charge. With good caking and highly swelling coals, variations in the rate of heating from 5° to 1° C. per minute do not modify their tendency to swell during the plastic stage. With coals such as the Derbyshire coals, which have only slight swelling power when rapidly heated (at, say, 5° C. per minute), this tendency is entirely suppressed when the rate of heating is slow, say 1° C. per minute. (See, for example, Slater, *Fuel*, 1927, **6**, 82.) With such a coal the comparatively rapid heating near the walls of the oven will cause swelling and the coalescence of the coal particles necessary for the production of a strong coke (see *Trans. Inst. Min. Eng.*, 1929, **76**, 200). The slow rate of heating (less than 1° C. per minute) near the centre of the oven will, however, cause no swelling of the coal there. Not only will the coke produced at the centre of the oven



No. 15. 45A. 28A. 22D.

PLATE X.—Derbyshire Cokes : External Views.

[To face p. 38.

Oven with "bottom-heat." Without "bottom-heat."

Coal Used:

33% Black Shale
67% Deep Hard

67% Black Shale
33% Deep Hard

67% Park-gate
33% Silk-stone

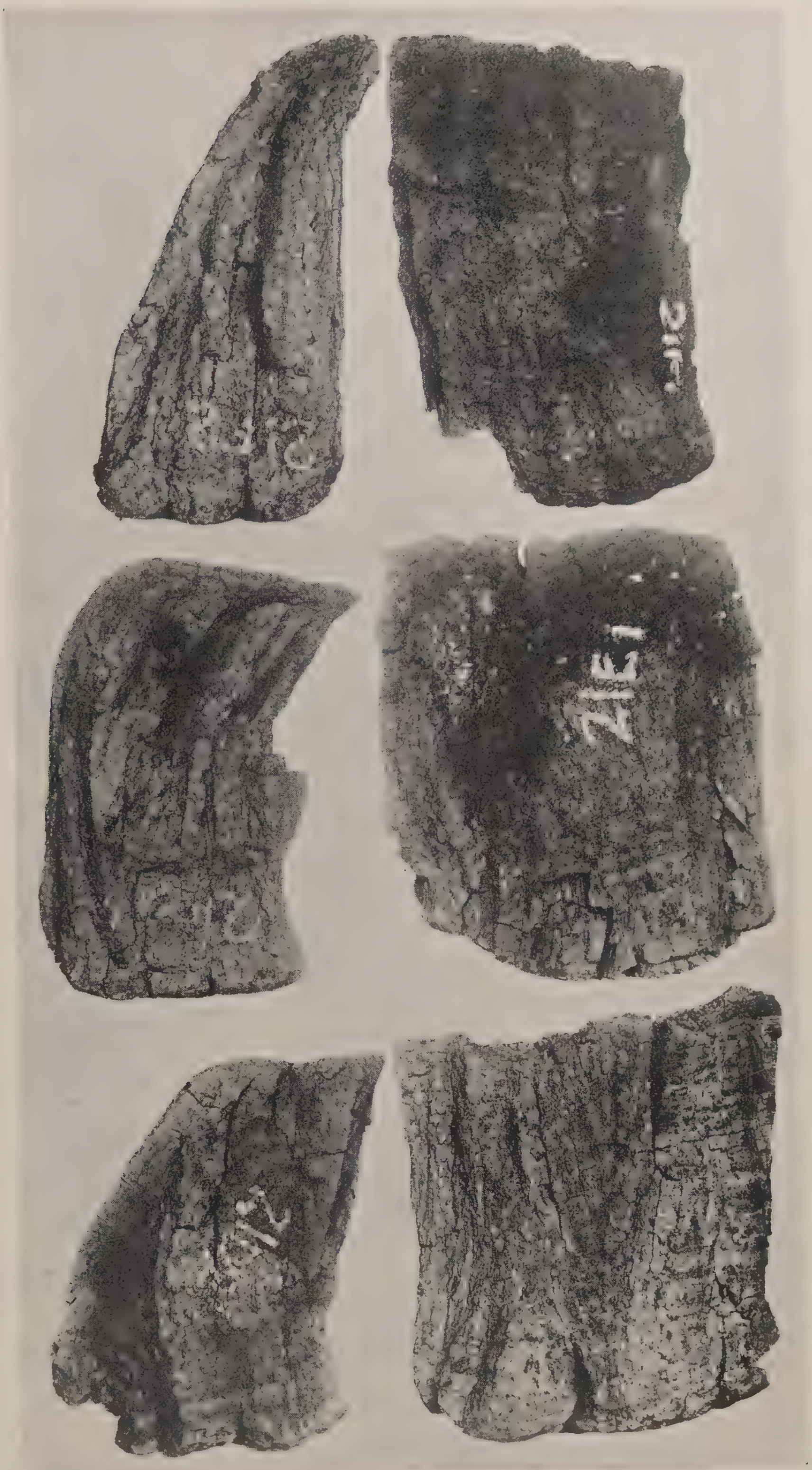
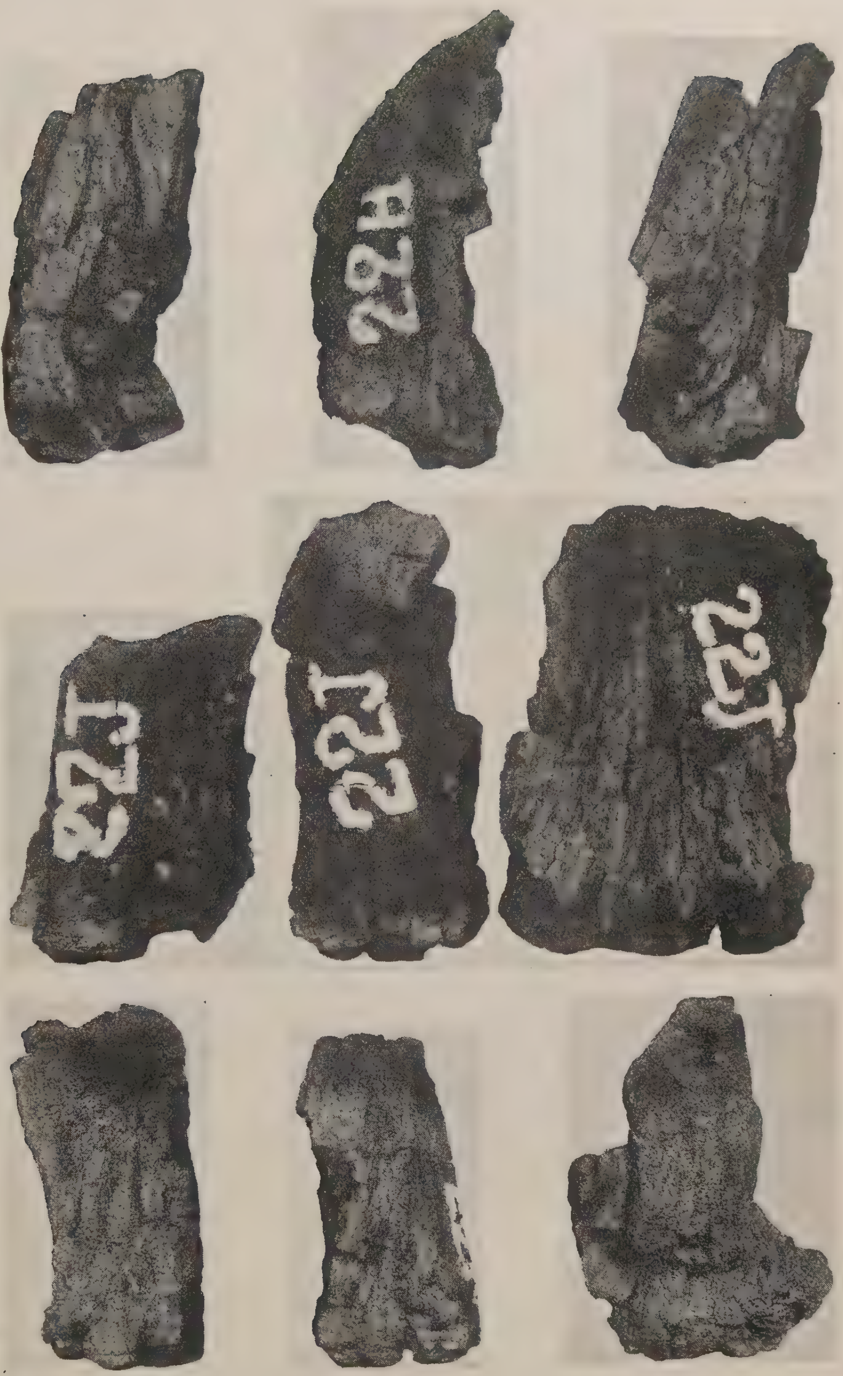


Plate XI.—Effect of Bottom Heat on Shape of Coke.



Coke
No. 22H,
26-hr.
coking-time.

Coke
No. 22J,
18-hr.
coking-time.

Coke
No. 22K,
13-hr.
coking-time.

PLATE XII.—Effect of Rate of Heating on Coke Shape.

[*To face p.* 38.

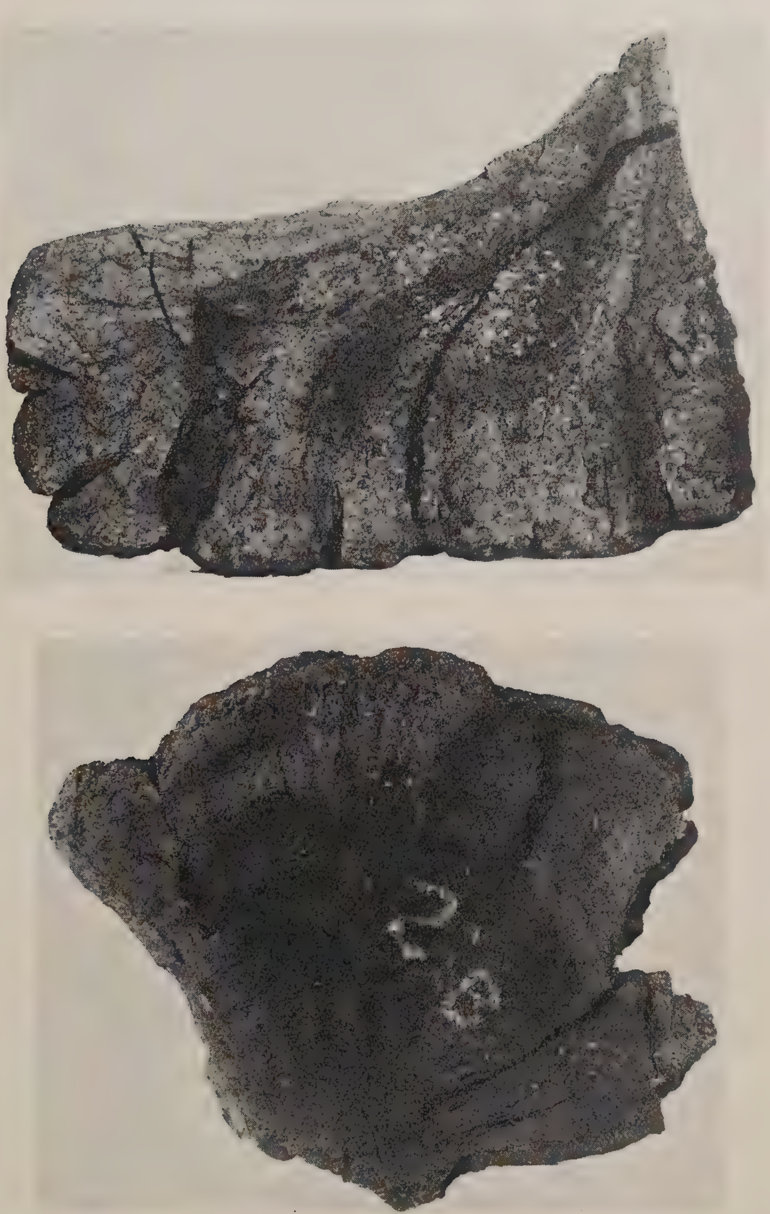


PLATE XIII.—Coke from Oven Sole (above) and Oven Top (below).

[*To face p.* 38.

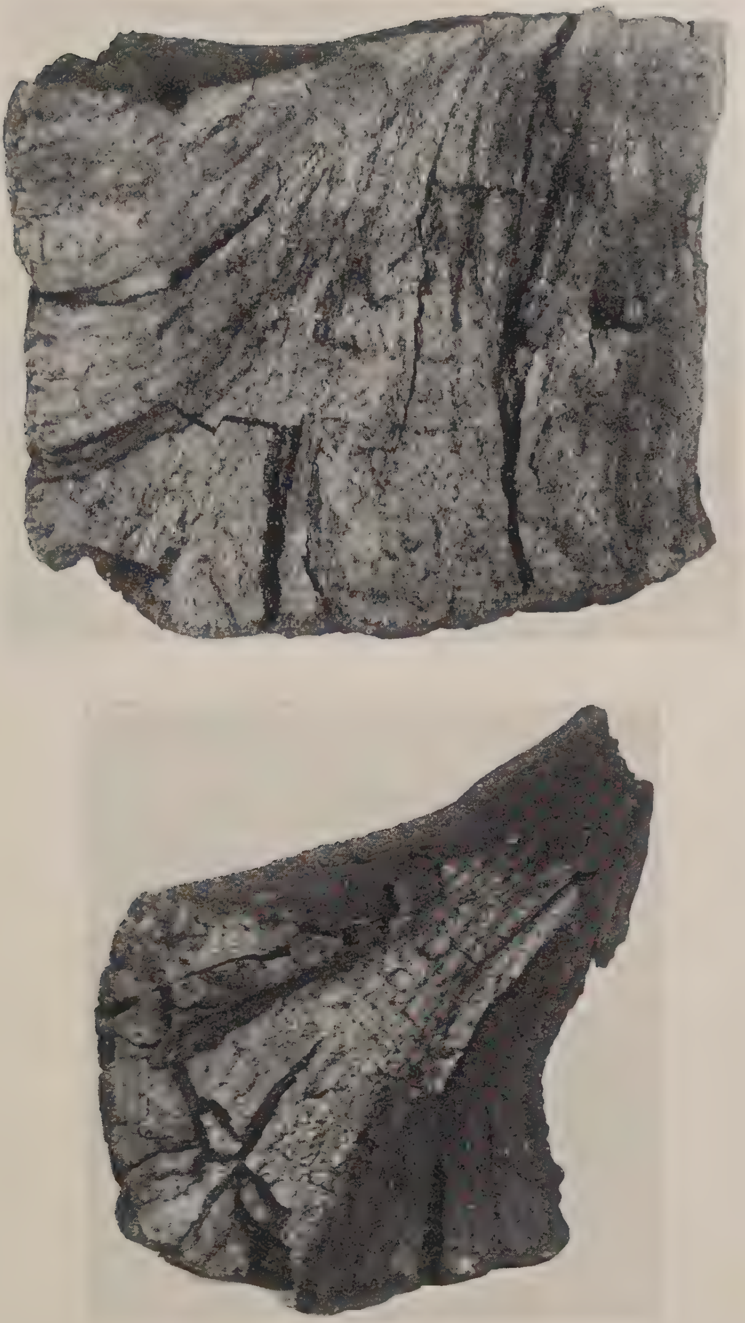


Plate XIV.—Coke from Oven Sole with Double Cauliflower End and Curved Fractures.

[*To face p.* 38.

F

be weaker than that at the walls, therefore, but, by reason of the greater shrinkage there, the curvature of the coke pieces will be emphasised.

If this is the correct interpretation of the inclination and curvature of the longitudinal shrinkage cracks in some cokes, it follows that the tendency of a coal to yield curved coke pieces would be accentuated by coking in ovens having excessive bottom heat. This deduction was tested by coking the same coals in two types of ovens, the one an old type Otto regenerative, vertical-flued oven with dividing header brick in the flues, and the other a horizontal-flued waste-heat oven. The former had marked bottom heat, whilst in the latter the centre flue was the hottest. The coking times, however, were not much different, namely 36 hours and 40 hours, respectively. Plate XI illustrates the cokes made in these two types of ovens from three mixtures of coking slacks. The first of each pair of cokes is that made in the "bottom-heat" oven. It will be seen that in each instance the curvature of the piece of coke is accentuated by the bottom heat.

Another deduction from the theory is that reduction in the width of the oven should improve the shape of the coke pieces, for, the rate of heating being increased, the resistance of the plastic layer to gas-flow would be increased (cf. Foxwell, *Fuel*, 1924, **3**, 126) and the transference of convected heat to the coal at the centre of the oven decreased. This would cause the shrinkage isotherms to approach more nearly to the ideal of two vertical parallel planes. There would also be less contrast between the rates of heating at the centre and at the walls of the oven, the centre-of-oven ends of the coke pieces being, in consequence, less fissured. On the other hand, the faster rate of shrinkage might produce more shrinkage cracks in the wall ends. The results of different rates of heating are illustrated on Plate XII for a Derbyshire coal coked in ovens of different widths, uniformly heated, giving coking times of 26, 18 and 13 hours. The tendency for curvature of the coke pieces is seen to be less the shorter the coking time.

The shapes of coke pieces so far considered are the normal shapes of the average contents of the oven. Coke from the oven sole has a well-marked inclination or curvature (see Plates XIII and XIV). This is due to the heat being transmitted to the charge from the bottom as well as from the sides. Shrinkage cracks form at right angles to the isotherms, which are parallel to the oven sole near its middle and to the walls at its sides. The resultant fractures are therefore at an angle of 45° to the sole. These give the coke formed there a typical appearance.

A photograph of coke from the top of an oven is shown on Plate XIII. It is only at the top of an oven that a strongly-swelling coal is free to swell, for at any layer elsewhere its tendency to do so is neutralised by a similar tendency of the layer of coal above it. The swelling occurs in plastic layers in vertical planes parallel to the oven walls, and, since the pressure due to it acts equally in all

UNIVERSITY COLLEGE
MINING
DEPARTMENT
NO... HAM.

directions, only the coke at the top of the oven shows signs of sponginess through swelling.

It may here be remarked that the pressure due to swelling, acting in a horizontal plane, presses the coke against the oven walls (where it frequently takes an imprint of the joints in the brick-work) until the coal at the centre of the oven has passed through the plastic stage. When the coke at the centre of the oven finally shrinks, the contraction across the width of the oven draws away the cauliflower ends from the walls and the coke can be discharged.

The effect on the size of coke of blending a non-coking material with a coking coal has already been considered (p. 22). It is pertinent to discuss here the reasons for the effects noted. Two main types of products are produced: (1) a dense coke with small pores, few fractures and a tendency to be brittle; and (2) a large coke, with few fractures, but friable. In both types of cokes the number of shrinkage cracks is small. The normal shrinkage process has therefore been modified in both. In the dense type swelling has not been entirely eliminated, but this can be done by using an excess of non-coking material. The large, friable type of coke then results. This is illustrated on Plates XV and XVI, which shows cokes prepared by blending a good coking coal with 5, 10, 15, 20, 30 and 40 per cent. of low-temperature coke breeze.

The effect of the breeze additions on the swelling power of the coal is shown in Fig. 11. It will be seen that the swelling power is completely destroyed by 40 per cent. of breeze. The hardness of the cokes, as indicated by the 1½-in. shatter indices, is recorded in Table XIV, the values for cokes produced by blending anthracite duff with the same coking coal being given for comparison.

TABLE XIV.—THE EFFECT ON THE HARDNESS OF COKES OF BLENDING NON-COKING MATERIALS WITH A COKING COAL

Addition to Coking Coal (per cent.).	Shatter Index (1½-in. Screen) of Coke from Blend with:	
	Low-temperature Coke Breeze.	Anthracite Duff.
Nil	86·7	86·7
10	86·9	85·2
20	89·2	88·1
30	88·0	89·6
40	84·1	85·9

So long as the blend retains some swelling power, the particles of non-coking material can coalesce with the coking coal, but when the swelling power has been entirely destroyed, the surfaces of the coking and non-coking ingredients of the blend can only be brought into intimate contact during the contraction of the charge and there is no true coalescence of the particles.

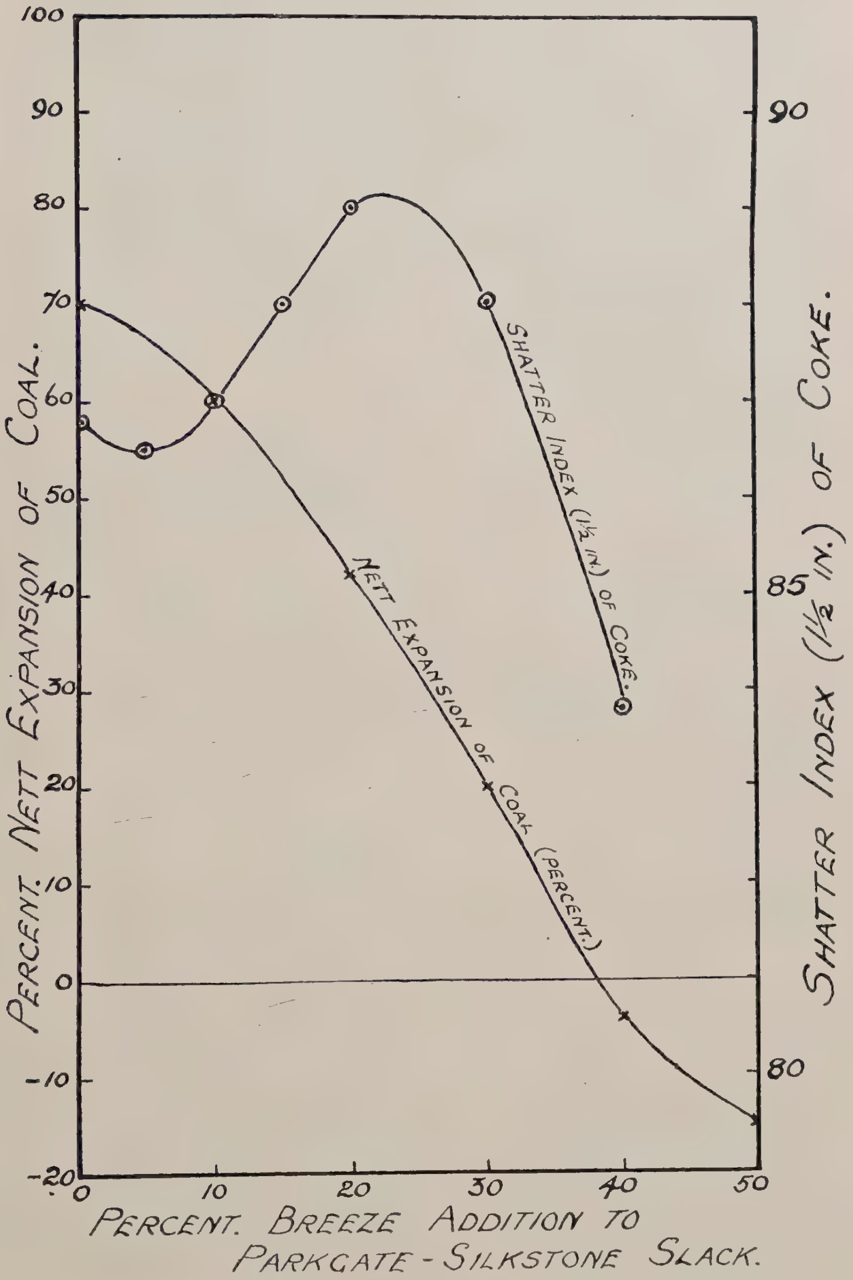
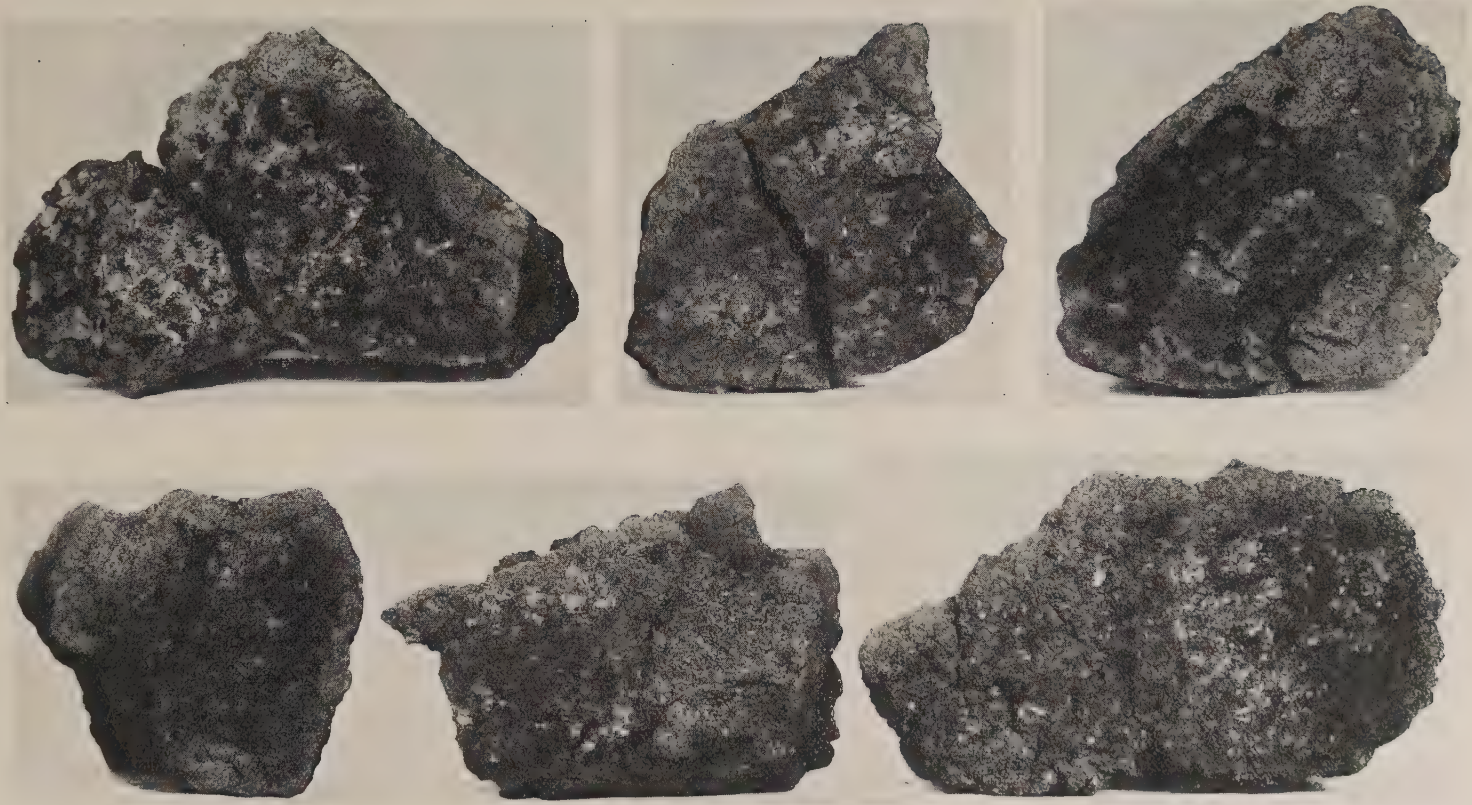


FIG. 11.—Effect of the Addition of Low-temperature Coke Breeze on the Swelling Properties of the Blend, compared with the Hardness of the Coke produced. (Cf. Plate XV and XVI.)

The particles of non-coking material form centres of contraction nearly uniformly distributed throughout the charge, not, as when a coking coal is used alone, at specific zones. There is, therefore, a high percentage of open pores, allowing free escape of volatile matter, and, the shrinkage being uniform, the pores are of small size. When the non-coking material is in excess, the size of the coke is increased, showing that the main shrinkage lines are few in number. The lack of firm cohesion between the particles of non-coking and coking material, however, causes innumerable small shrinkage cracks which render the coke friable. This is well illustrated by Plate XVII, which shows sections of cokes made from: (No. 38A) a poorly coking West Yorkshire coal; (No. 38C(iv) the same coal with 22 per cent. of low-temperature coke breeze; and (No. 38A.s) the slurry from the same coal, to which reference will be made later. Coke No. 38A has the inclined outline and type of fracture common to cokes from poorly coking coals; coke No. 38C(iv), which came from the oven in large lumps up to 2 ft. in dimension, contains numerous small shrinkage cracks irregularly disposed. Such a coke does not break easily along major fractures, but loses small pieces when it is dropped or subjected to shearing (abrasive) forces.

The improvement in the quality of coke obtained by blending suitable amounts of a non-coking material with a coking coal has usually been ascribed to the reduction in the volatile matter contents of the charge, the amount of shrinkage being thereby reduced. In general, however, the non-coking materials used for blending (such as low-volatile coals and low-temperature coke breeze) begin to lose their volatile matter at temperatures above the plastic range of the coking coal, and may then lose as much as does the coking coal itself. It seems more probable that the main effect of the non-coking material is to provide definite centres of contraction. For example, coke No. 38A.s (Plate XVII), made from the slurry of a poor coking coal, was almost as hard as the best Durham cokes, being of dense structure and blocky, with a silvery lustre. The slurry contained about 4 per cent. of fusain, half of which was concentrated in the dust passing a 200-mesh sieve. Assuming that the average size of these dust particles was $\frac{1}{250}$ in., there would be about 40 million of them per gram, or about one hundred times as many per gram as the particles of low-temperature coke breeze (80 per cent. through $\frac{1}{8}$ in.). The small proportion of this non-coking material in the slurry would barely affect the volatile matter content of the charge or the swelling power of the coal, but each of the many small particles would act as a centre of contraction and uniform shrinkage would occur. This suggestion is borne out by further experiments, which are fully described later, in which low-temperature coke breeze ground to pass a 200-mesh sieve was used. As little as $2\frac{1}{2}$ per cent. of this fine dust blended with the charge produced a dense and blocky coke. Audibert (*Fuel*, 1929, **8**, 237), from laboratory experiments, has come to a similar conclusion as regards the effect of small particles of a non-coking material in producing uniform shrinkage, an effect comparable with that of

No. 29 I(*b*) i. 29 I(*b*) ii. 29 I(*b*) iii.

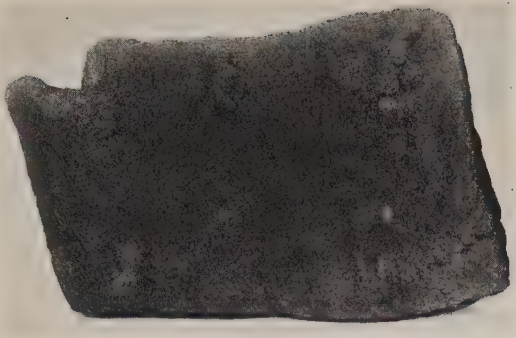


No. 29 I(*b*) iv. 29 I(*b*) v. 29 I(*b*) vi.

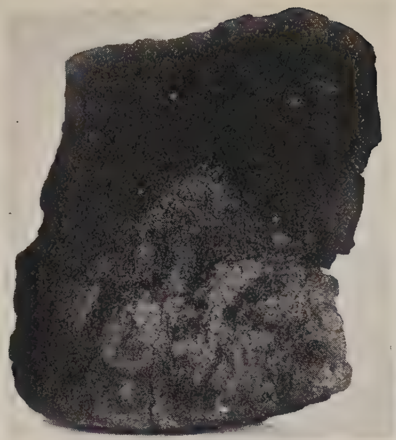
Plate XV.—Effect of Blending Low-temperature Coke Breeze on Coke Structure: Cauliflower End Views. (See also Plate XVI.)

[*To face p.* 42.

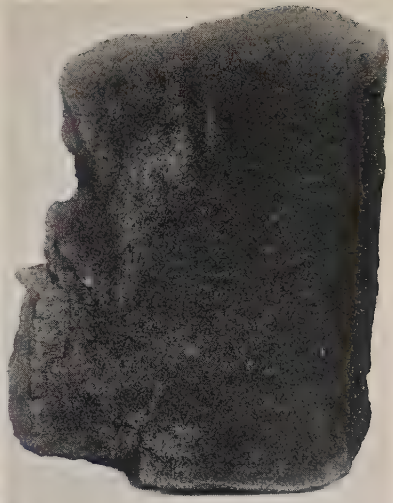
No. 29 I(*b*) i.



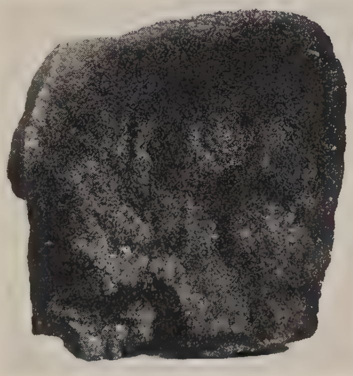
29 I(*b*) ii.



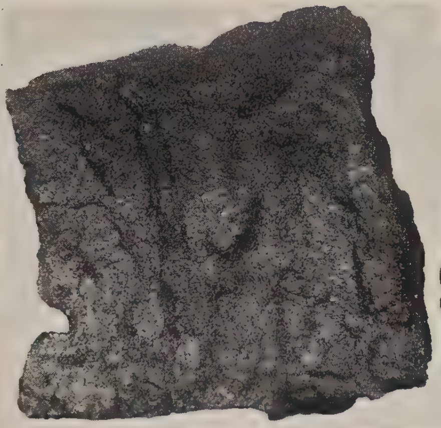
29 I(*b*) iii.



No. 29 I(*b*) iv.



29 I(*b*) v.



29 I(*b*) vi.

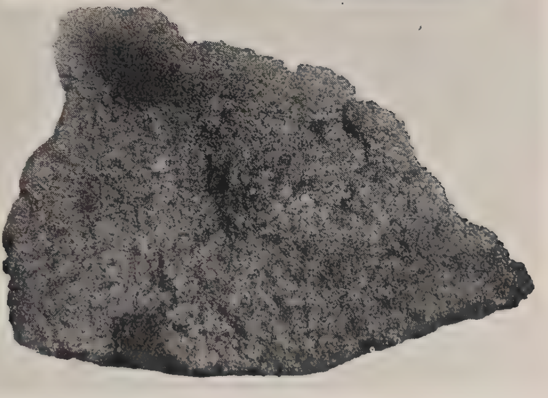
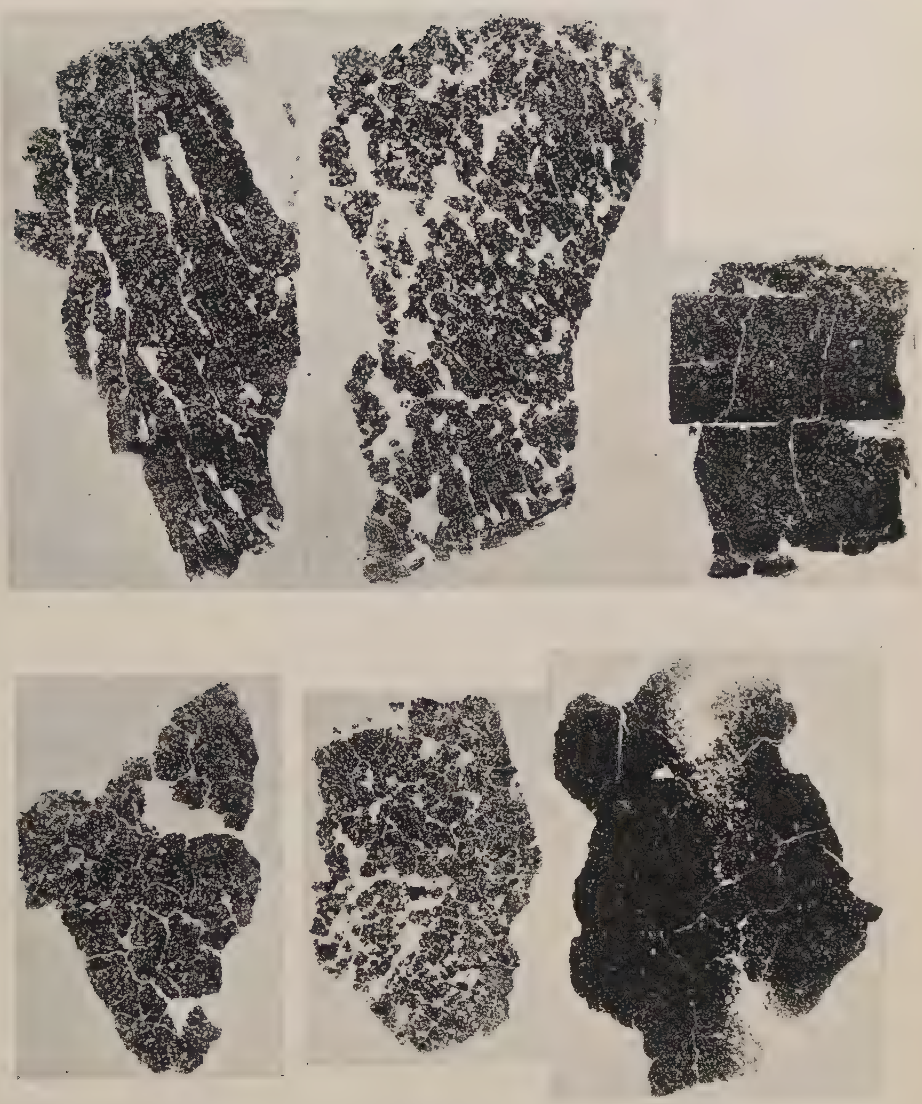


PLATE XVI.—Effect of Blending Low-temperature Coke Breeze on Coke Structure. Longitudinal Views. (See also Plate XV.)

Coke No.	Per cent. of breeze.	Coke No.	Per cent. of breeze.
29 I(*b*) i	5	29 I(*b*) iv	20
29 I(*b*) ii	10	29 I(*b*) v	30
29 I(*b*) iii	15	29 I(*b*) vi	40

[*To face p.* 42.


Longitudinal Section.
Transverse Section.

Coke No. 38A. 38C (iv). 38A.s.

PLATE XVII.—The Effect of Blending on Coke Structure: Sections.

[*To face p.* 42.

" grog " on the shrinkage of clay (cf. Le Chatelier, "La Silice et les Silicates ").

Although many of the foregoing observations relate specifically to the internal fractures of coke, they are of moment with regard to the shape of the coke pieces, our immediate concern. For the shrinkage lines determine the position of the major fissures and these outline the shapes of the coke pieces.

To sum up, the coke from good coking coals is nearly rectangular in longitudinal section and roughly hexagonal in cross-section, the pieces being large and blocky. A similar shape of coke can be produced from a poorly coking coal by blending with it a suitable (small) amount of a finely-divided non-coking material. Whilst this blending reduces the resistance of the plastic layer to the passage of gas (and thus tends to reduce the coking time), it so profoundly modifies the character of the shrinkage, as compared with that obtaining with a good coking coal alone, that there is no tendency for the formation of major shrinkage cracks such as impose curved outlines on the coke pieces. It should be possible, therefore, by proper choice of oven width (and rate of heating), and by judicious blending, so to control the size and shape of the coke pieces that the coke from almost any coking coal will be hard, blocky and but little fractured.

Appearance.—The silvery-grey lustre of Durham beehive coke was at one time much prized by metallurgists, and the duller appearance of by-product oven coke for long caused it to find disfavour for blast-furnace use. Similarly, at the present time a coke with a silvery-grey lustre is demanded by many iron-foundrymen and crucible-steel melters. There may be some justification for this, but, our main concern being blast-furnace coke, we will defer discussion of it.

South Wales cokes, which are generally considered to be of the highest quality, superior even to Durham cokes, usually have a dull appearance, with no silvery lustre. But, South Wales cokes apart, cokes of dull black appearance are not held in high esteem. Durham cokes and the best Yorkshire cokes have a grey colour, which persists throughout their mass.

It is natural to assume that the colour of a coke is affected by the path of travel of the gases in the oven. As previously explained, Durham and Yorkshire coking coals usually afford a plastic layer of high resistance to gas passage, so that the gas produced on the coke side of that layer passes mainly through the coke and is partly decomposed, depositing carbon. With the poorer coking coals the gases pass more freely through the plastic layer and there is less carbon deposition within the coke. As will be shown later, the carbon deposited in this manner is of low reactivity. It may therefore act as a resistant layer tending to reduce " solution " loss in the blast furnace or the cupola. From this point of view there may be some justification for preference for a coke with a silvery-grey colour (if it has been made from a high-volatile coal), but that a grey colour is not an essential index of quality is evident from the good black South Wales cokes.

South Wales cokes, besides being dull in appearance, often have a granular surface. A similar surface has been noted on cokes made from the "hards" (durain) of Yorkshire coals, or from blends of a Yorkshire coking coal with anthracite. The general resemblance of these cokes extends to their size (cf. Plates XVIII and XIX, with Plate VI). Cokes made from the Mountain Mine seam, Lancashire, are also dull and granular in appearance. Similar properties have been noted in by-product cokes from the Deep Hard seam, Derbyshire.

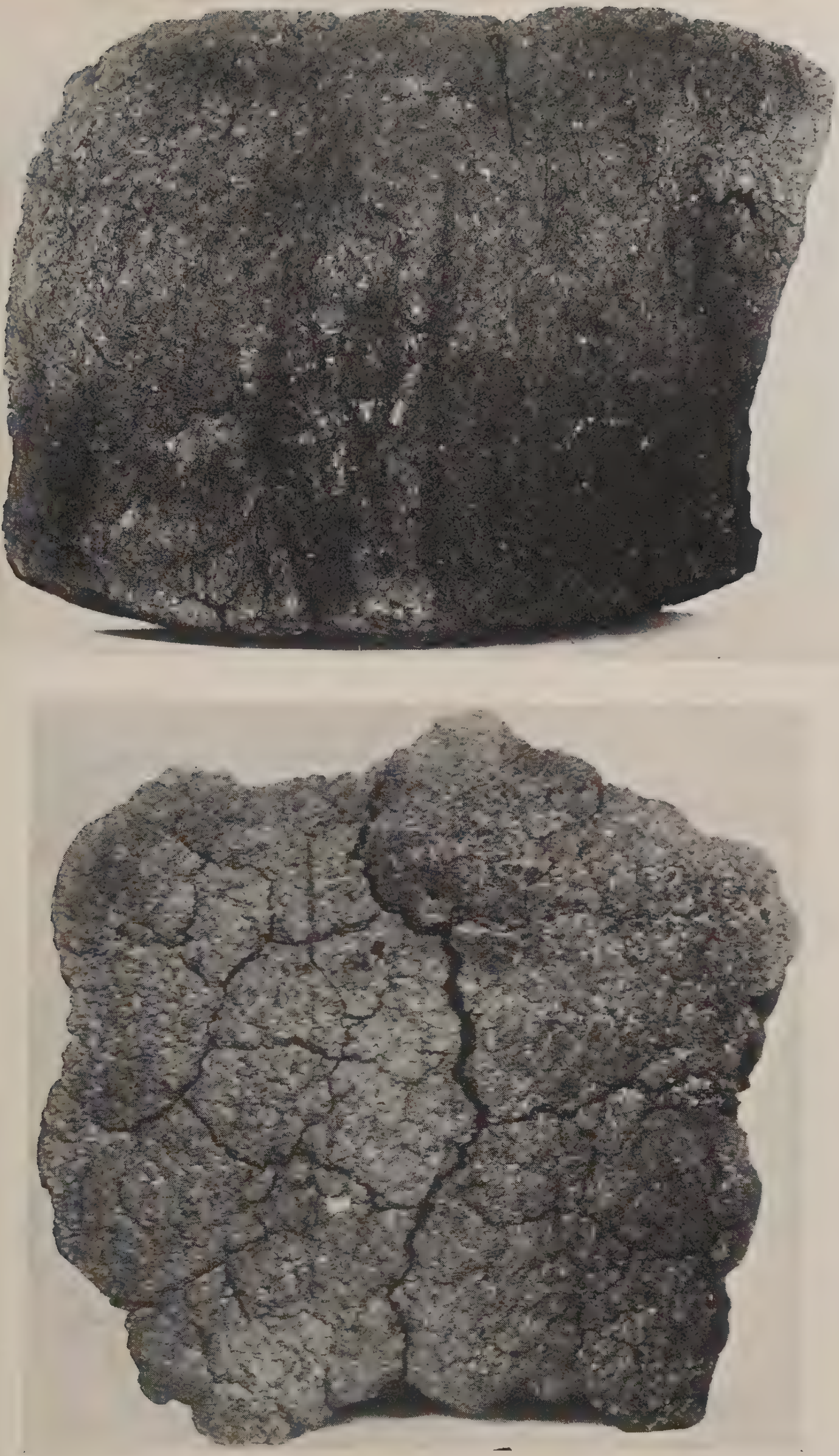
For all of these cokes the coal charges are weakly swelling and therefore dependent on contraction phenomena to cause cohesion of the coal particles. Since there is but little swelling, "fusion" (intermingling of the molecules of adjacent coal particles) does not occur and granular surfaces result. Such surfaces are rather more readily abraded than the smooth surfaces of cokes from swelling coals.

Durham cokes usually have smooth surfaces. Longitudinal fissures are rare, but transverse cracks are often noticeable (see Fig. 1). The cauliflower ends are usually well curved and smooth (see Plate VIII).

Yorkshire cokes vary considerably in appearance. The best have smooth surfaces, but many show longitudinal fissures. The cauliflower ends of the better cokes are well rounded and smooth (see Plate IX).

Derbyshire cokes sometimes have granular surfaces and all have longitudinal fissures. The cauliflower ends are frequently flat and granular. Flatness of the cauliflower ends appears to be characteristic of cokes from weakly swelling coals (see Plate X). A granular surface of the cauliflower end apparently arises, when a compressed charge of coal is used, in the following manner: The cake is an inch or two narrower than the oven. On heating, gas and steam loosen the outer edges of the cake and particles of coal fall off, lessening the density of the outer layer of coal. Owing to the low swelling-power of the coal, insufficient compression occurs during coking to consolidate the outer layers and friable cauliflower ends result.

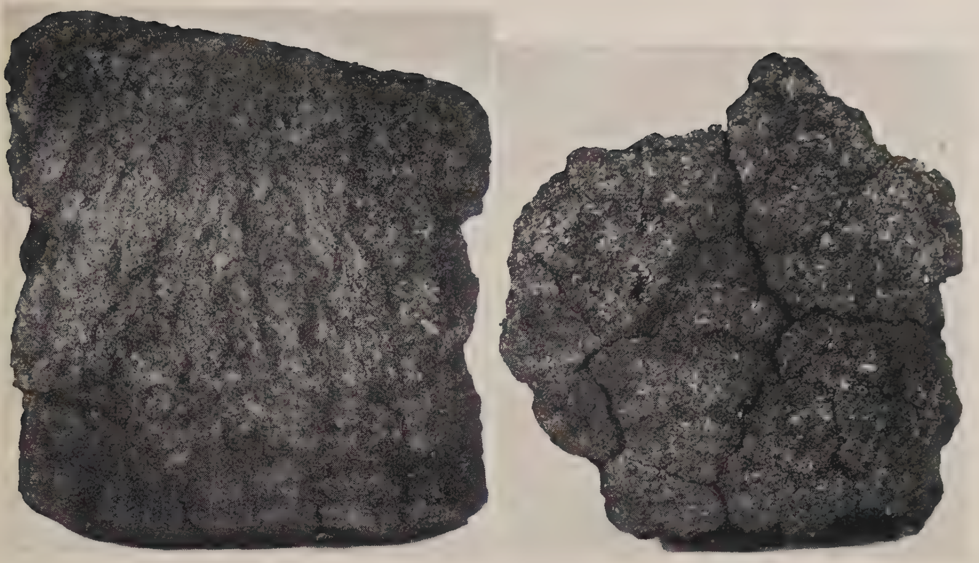
Fractures.—Major fractures are parallel to the shrinkage cracks which outline the shapes of the coke pieces. They therefore extend through the length of the coke pieces. If a cross-section of a much-fractured coke is examined (see, for example, Fig. 12), it will be seen that the internal fissures outline a series of hexagonal pieces, these internal fissures having been caused by shrinkage in just the same way as the major fissuring in the oven that outlined the shapes of the coke pieces. The greater the number of internal fissures in a piece of coke the weaker it is. Although the trained eye can form a fair judgment with regard to the probable degree of fissuring of a piece of coke from its external appearance, it is better



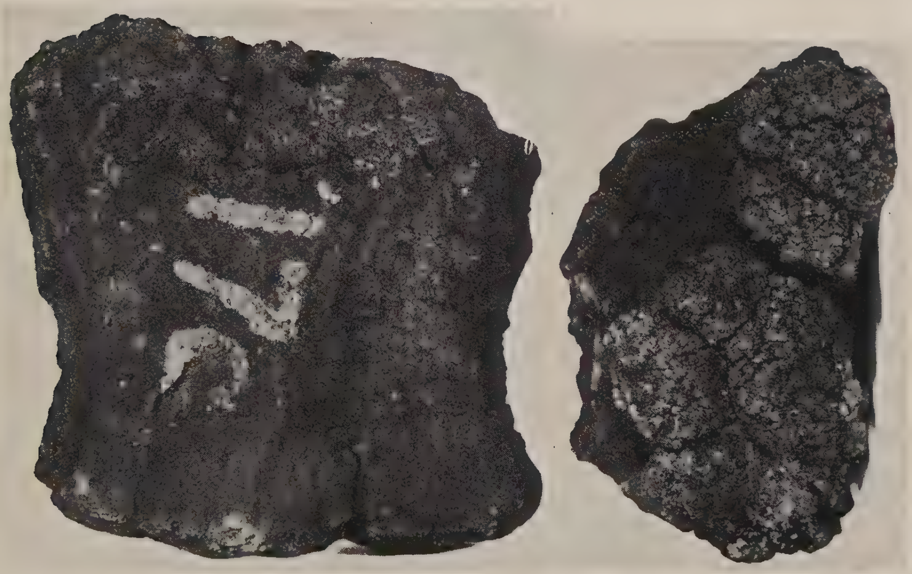
No. 9.

PLATE XVIII.—Massive Coke Produced by Blending Coking Coal with Anthracite Duff. (Cf. Plate VI.)

[*To face p.* 44.



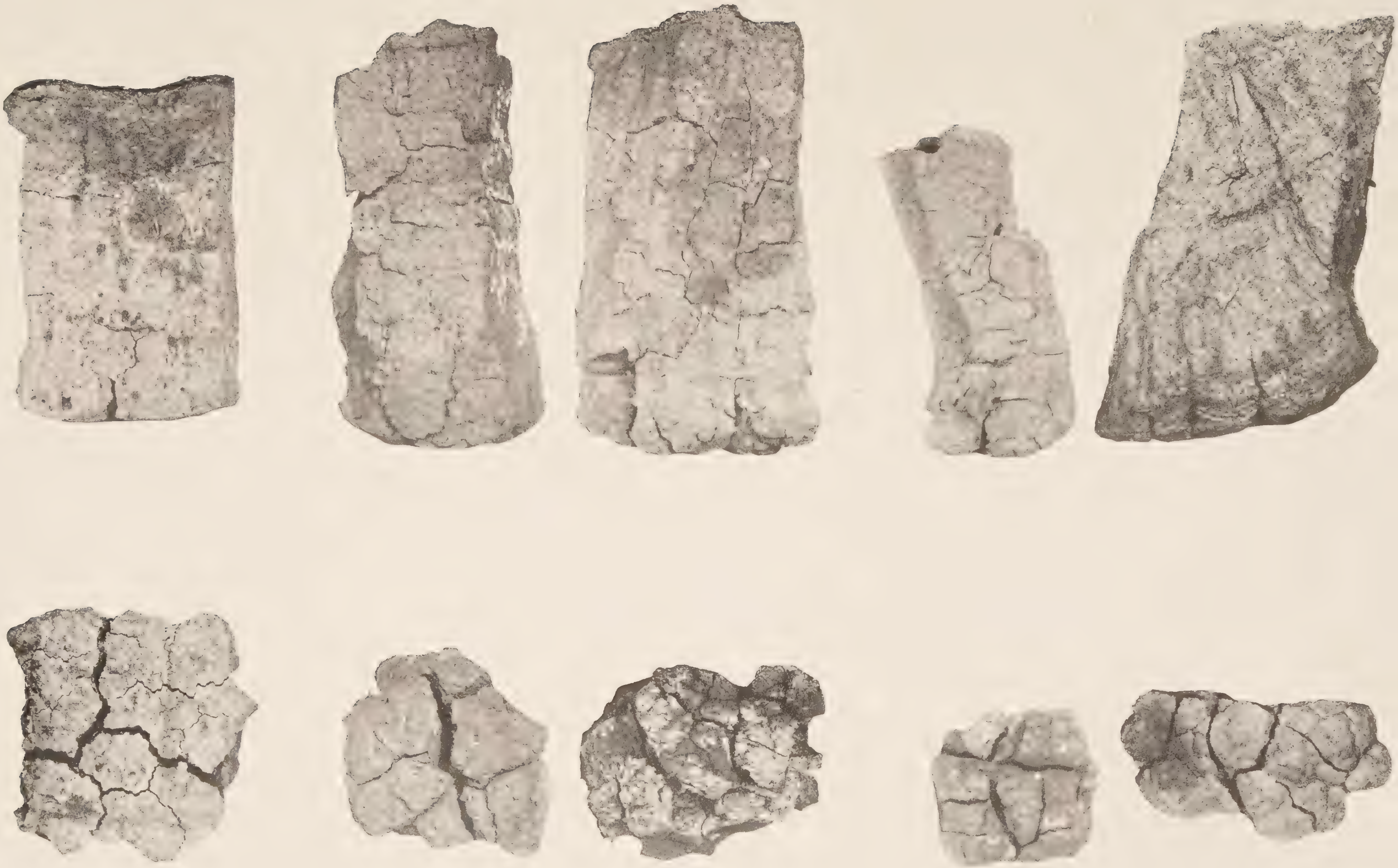
No. 17D (Barnsley Hards).



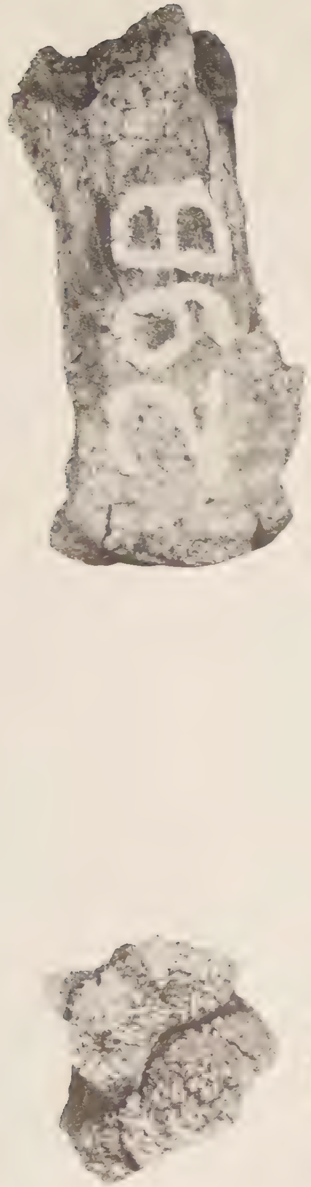
No. 17C (Parkgate Hards).

PLATE XIX.—Massive Cokes Produced from Ground Hards. (Cf. Plate VI.)

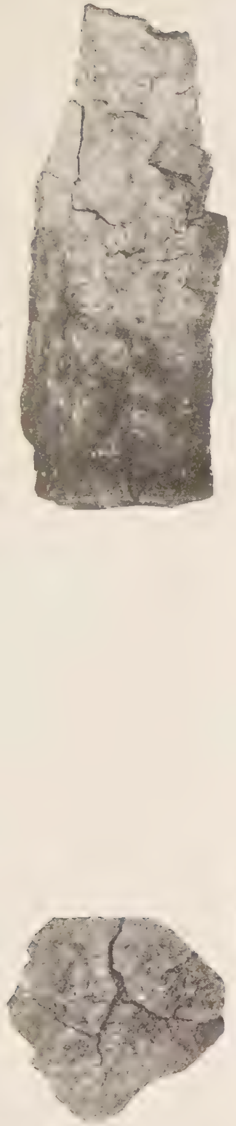
[*To face p.* 44.



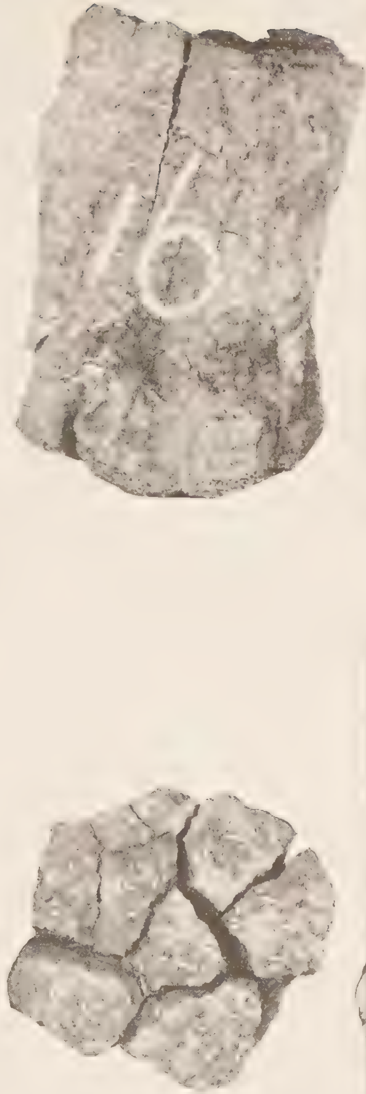
Coke No.	39.	30B.	41.	2.	17K.
Shatter Index (1½-in.)	97.	95.	93.	90.	89.



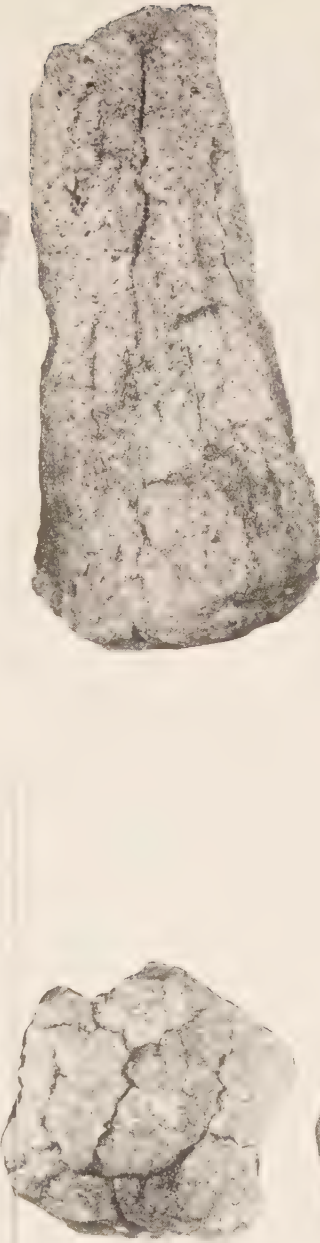
29B.
87.

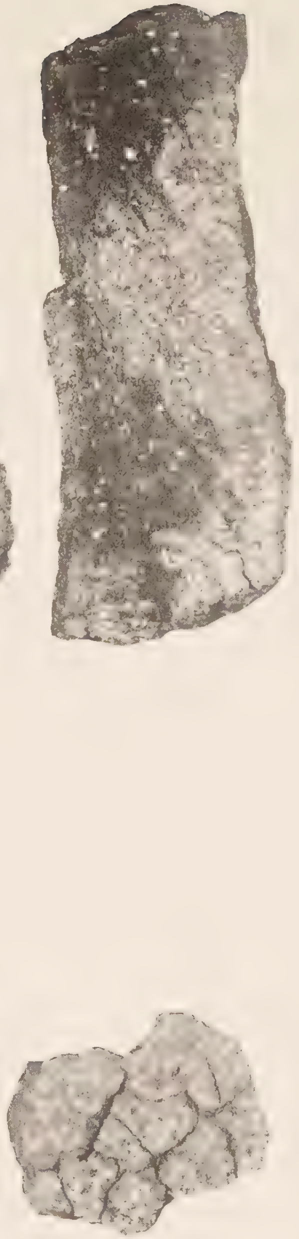

5.
85.

18E.
84.

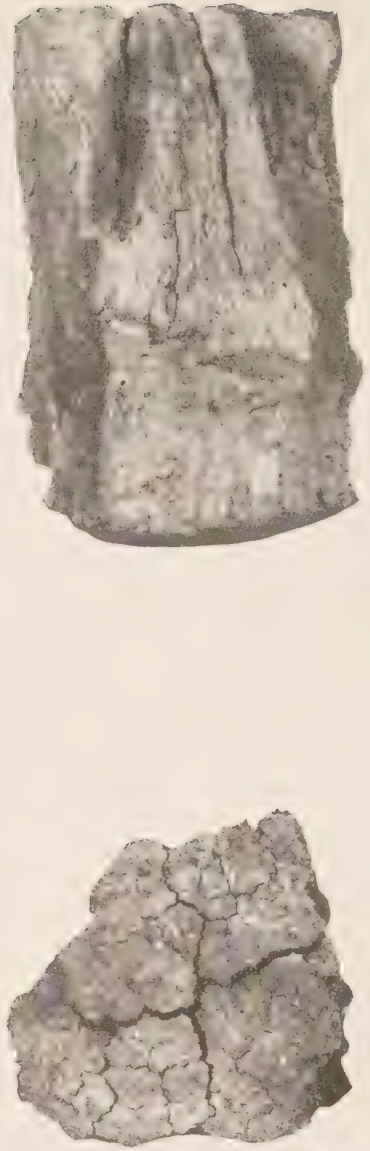


16.
83.


17G.
82.


18I.
81.

4.
80.


29A.
79.

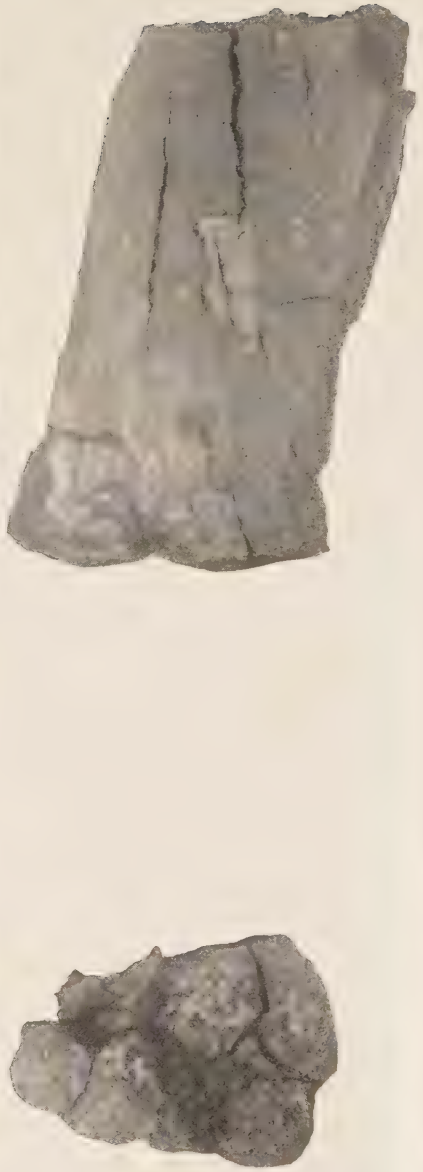
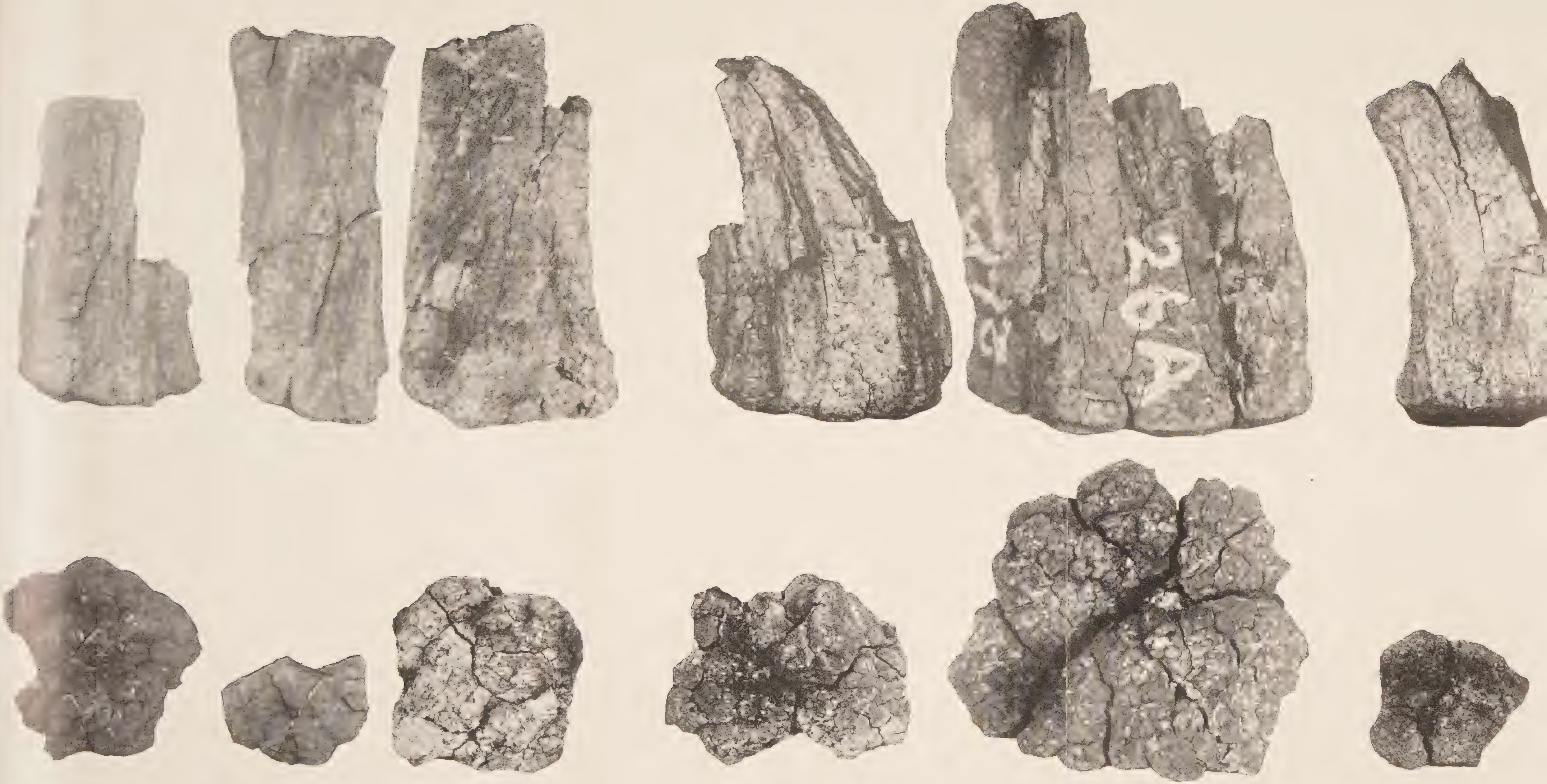

18C.
77.

Plate XX.—Comparison of External Appearance of a Series of



29D. 76.

21B. 75.

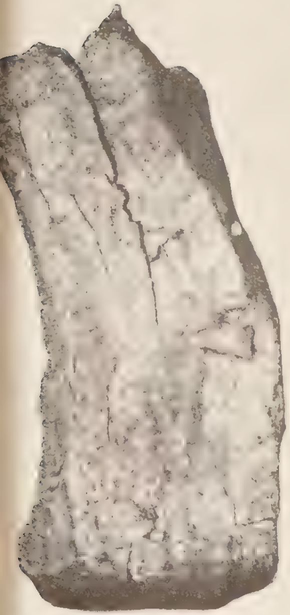
17I. 73.

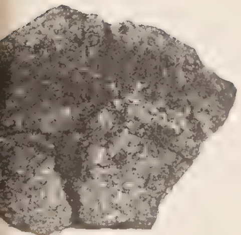
28D. 72.

26A. 71.

23B. 69.

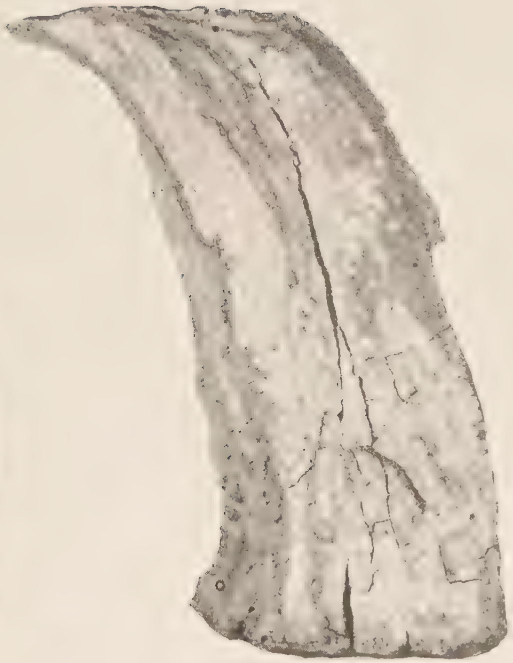
Cokes Arranged in Order of Relative Hardness. (Cf. Plate XXI.)

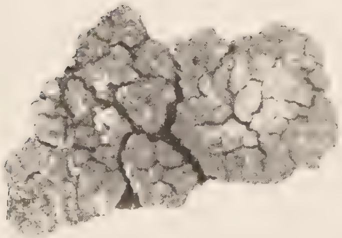




23B.

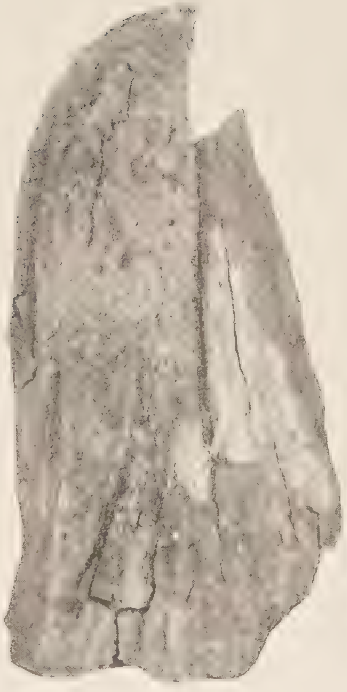
69.

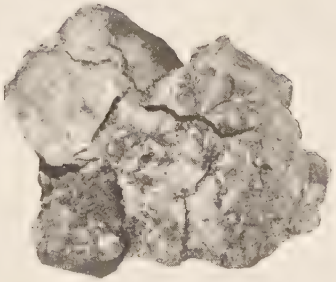




28A.

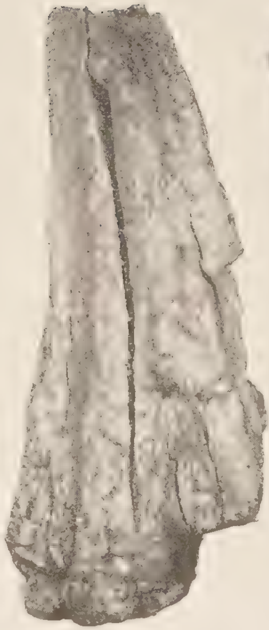
67.

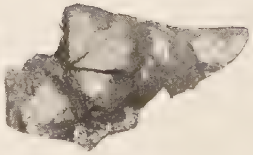




15.

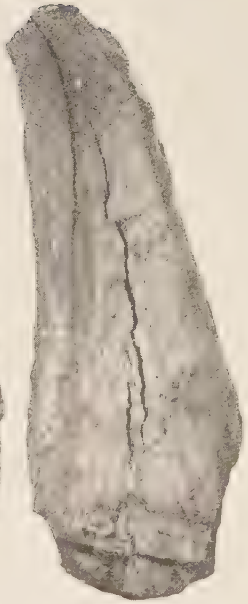
66.

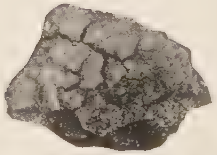




37.

62.





22C.

59.

[*Between pp.* 44 *and* 45.

to examine a section. This may be either a rough broken face (see Plates I and II) or a ground face that has had its fractures filled in with a white composition (see Plates III and IV) by the method devised by H. J. Rose (*Journ. Ind. Eng. Chem.*, 1925, **17,** 925) and used by him for a study of the macro-structure and micro-structure of cokes. We have used the method mainly for the study of the internal fissuring of coke pieces and their general macro-structure, which does not demand such careful grinding and polishing as does the preparation of specimens for microscopic examination. The modified Rose's method we have used is described in detail in an appendix to this chapter.

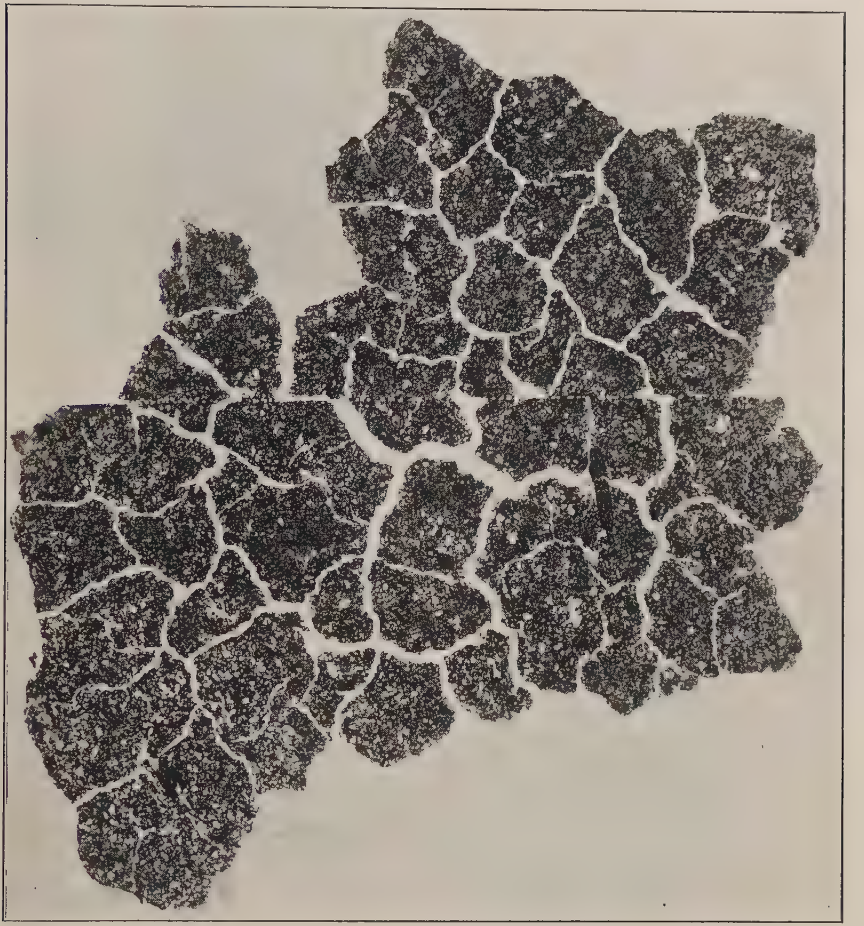
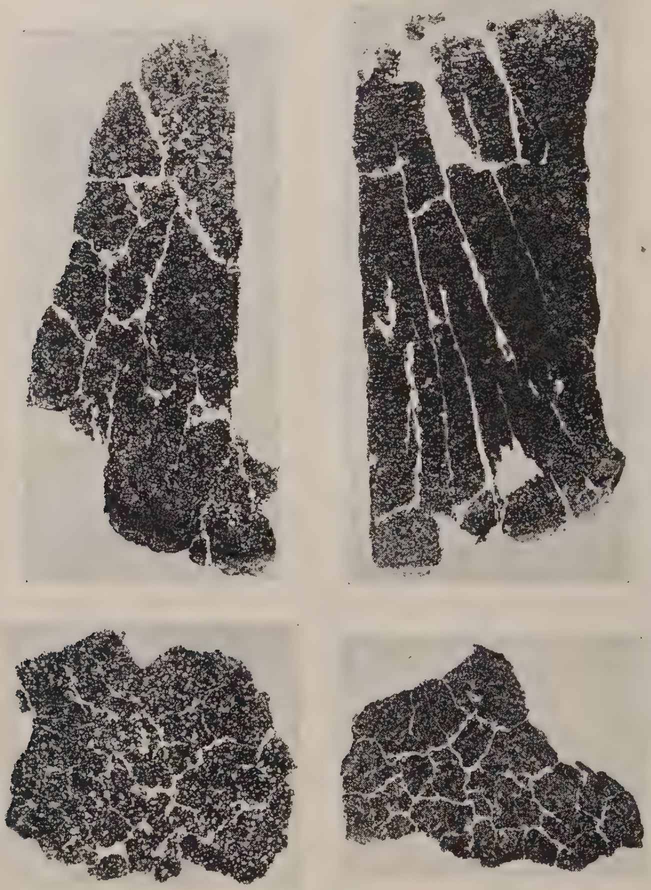


FIG. 12.—Transverse Section of Much-fractured Coke (No. 15, Derbyshire).

The usefulness of the method may be judged from some examples. On Plates XX and XXI, a series of longitudinal and transverse sections is compared with a series of photographs showing the external appearance of the same pieces of coke. The cokes have been arranged in decreasing order of hardness with nearly equal small differences between each, as indicated by their "shatter index" ($1\frac{1}{2}$-in. screen), a description of which is given in Chapter VII. It is clear that the hardest cokes have the least fractures and the weakest cokes the most. It is not suggested that cokes differing in their shatter index by 1 would necessarily disclose differences in the amount of internal fissuring. The error inherent in shatter testing, and the error as regards the degree of fissuring that must arise through the choice of one piece of coke only for examination, preclude such a possibility. Moreover, the internal fractures affect the hardness of the coke not only by reason of their frequency, but also by virtue of their

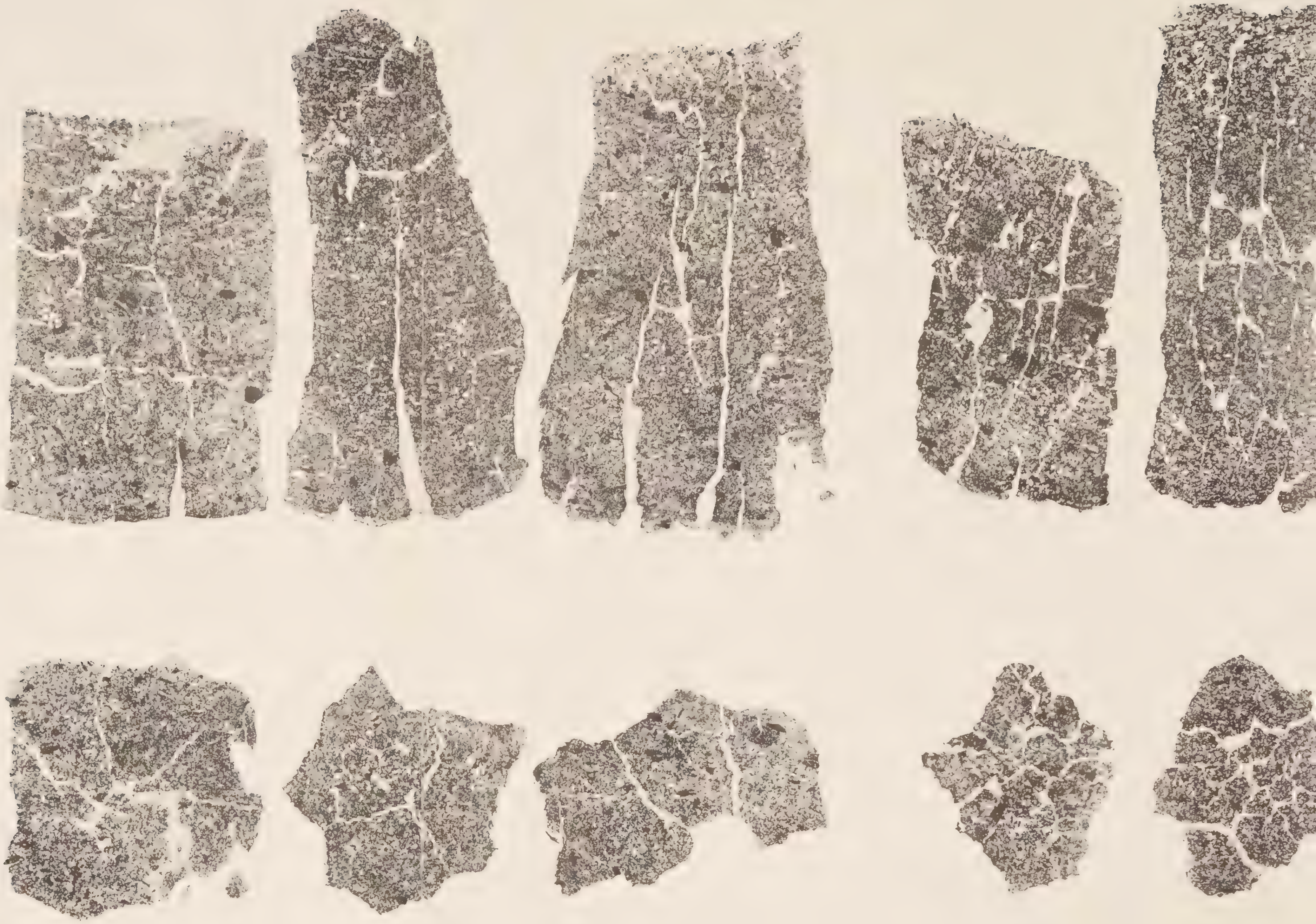


No. 17A. No. 17B.

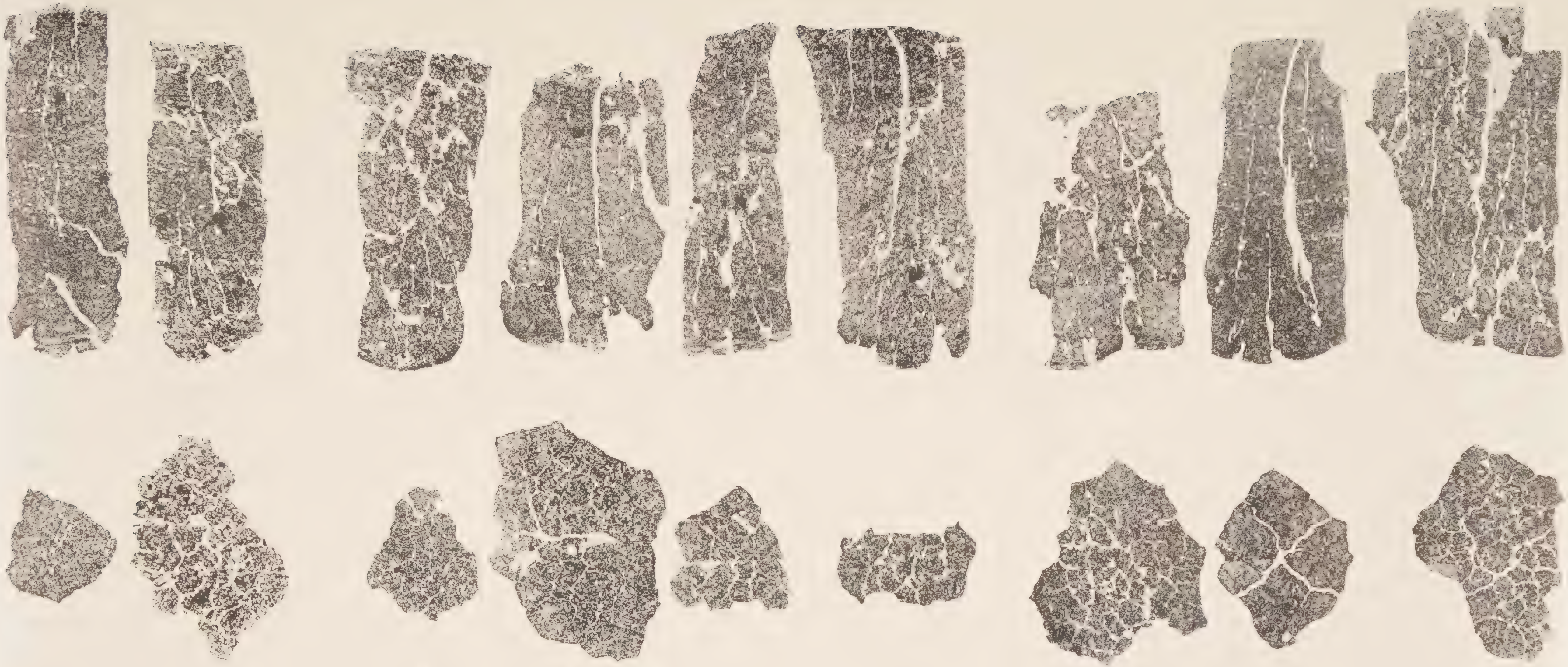
FIG. 13.—Comparison of Fracturing of Coke made from Top-charged (17A) and Compressed Coal (17B).

Longitudinal Section.

Cross Section.



Coke No.	39. (S. Wales.)	30B. (Durham.)	41 (Durham.)	2. (Durham.)	17K. (S. Yorks.)
Shatter Index (1½-in.)	97.	95.	93.	90.	89.



29B. (S. Yorks.) 87.

5. (Durham.) 85.

18E. (S. Yorks.) 84.

16. (Lancs.) 83.

17G. (S. Yorks.) 82.

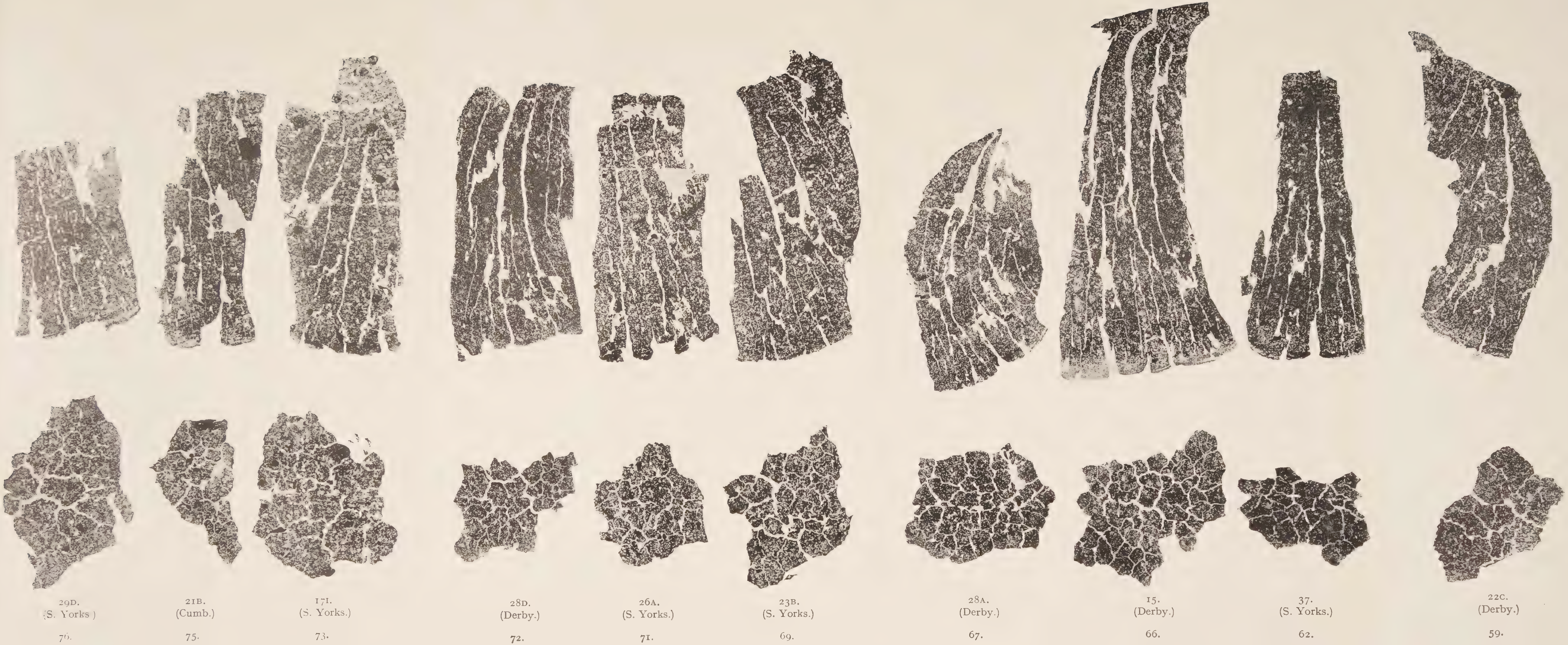
18I. (S. Yorks.) 81.

4. (S. Yorks.) 80.

20A. (S. Yorks.) 79.

18C. (S. Yorks.) 77.

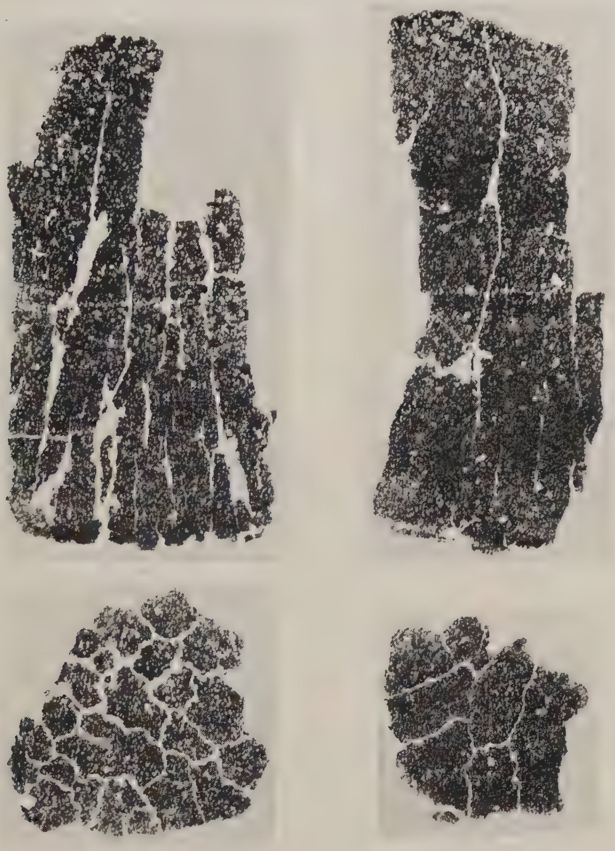
PLATE XXI.—The Relationship between Coke Hardness and the Degre


29D.
(S. Yorks.)
76.
21B.
(Cumb.)
75.
17I.
(S. Yorks.)
73.
28D.
(Derby.)
72.
26A.
(S. Yorks.)
71.
23B.
(S. Yorks.)
69.
28A.
(Derby.)
67.
15.
(Derby.)
66.
37.
(S. Yorks.)
62.
22C.
(Derby.)
59.

of Fissuring. (Cf. Plate XX. in which the same series of cokes is used.)

[*Between pp.* 46 *and* 47.

definiteness and the extent to which they penetrate to the outside of the piece of coke. Nevertheless, Plate XXI shows that cokes of the same degree of hardness are similar as regards their degree of fracturing, and that the gradation is fairly regular from the hardest to the weakest. On the other hand, no such gradation can be detected from the external appearance of the pieces of coke.



No. 36A. No. 36B.

FIG. 14.—Comparison of Fractures of Cokes made from Straight Coal (36A) and a Blend with Low-temperature Coke Breeze (36B).

Certainly, the hardest cokes are, by their appearance, superior to the weakest, but those midway in the series cannot be differentiated.

Either the longitudinal or the transverse section of a piece of coke serves from which to form a judgment as to the degree of fissuring, but the transverse section is often the more informative. Throughout Part II of this Report frequent use of such sections will be made to illustrate different points regarding the quality of cokes. Two examples may be quoted here.

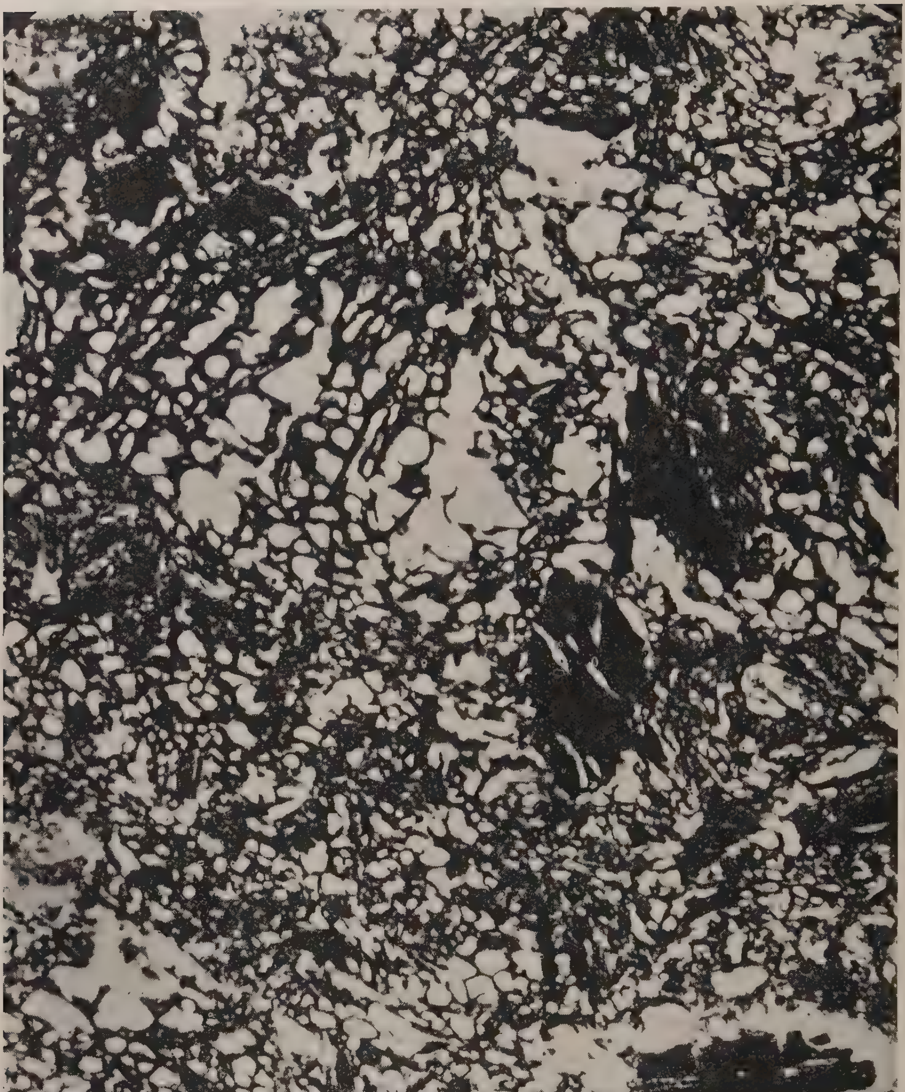


Fig. 15.—Micro-structure of Coke No. 1, S. Wales (× 6).

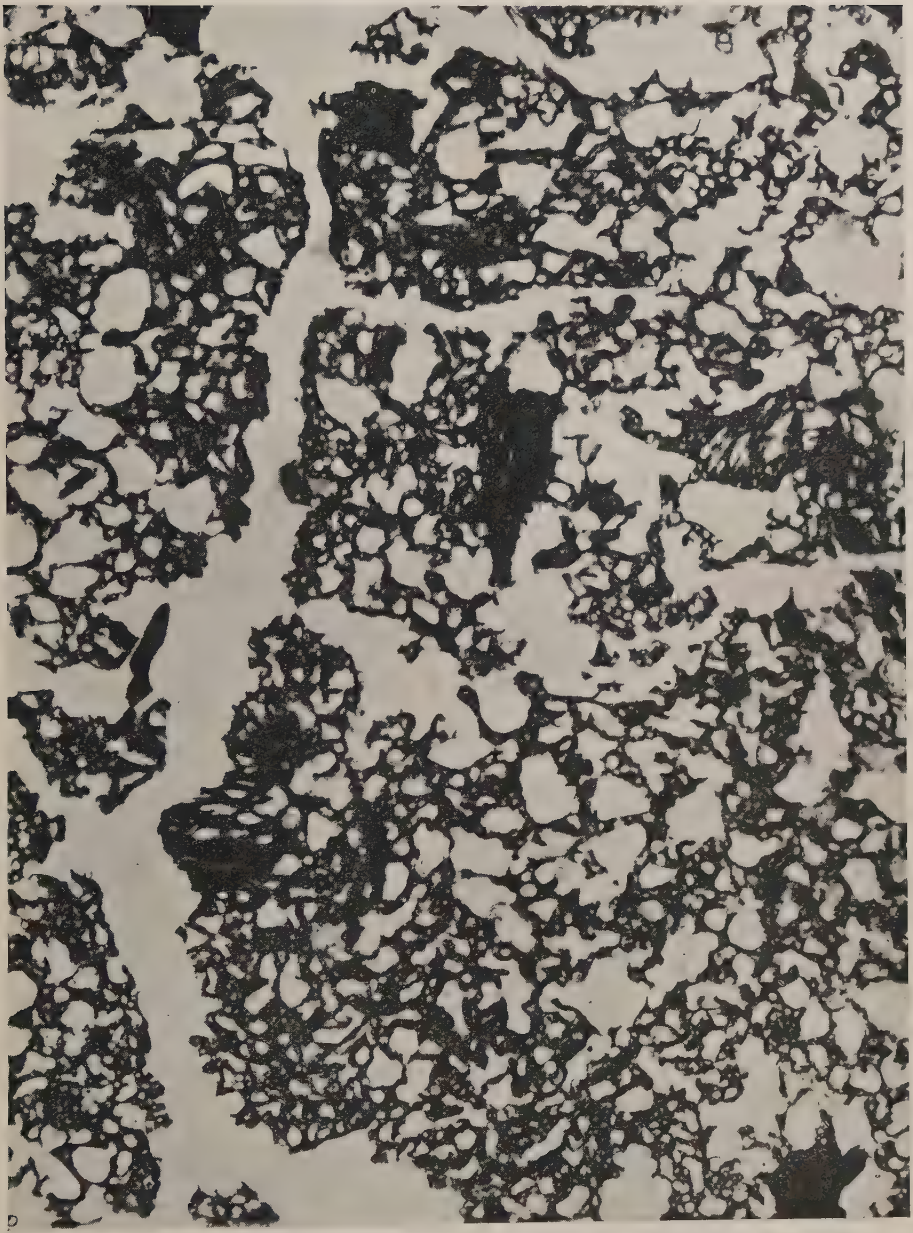


FIG. 16.—Micro-structure of Coke No. 2, Durham (× 6).

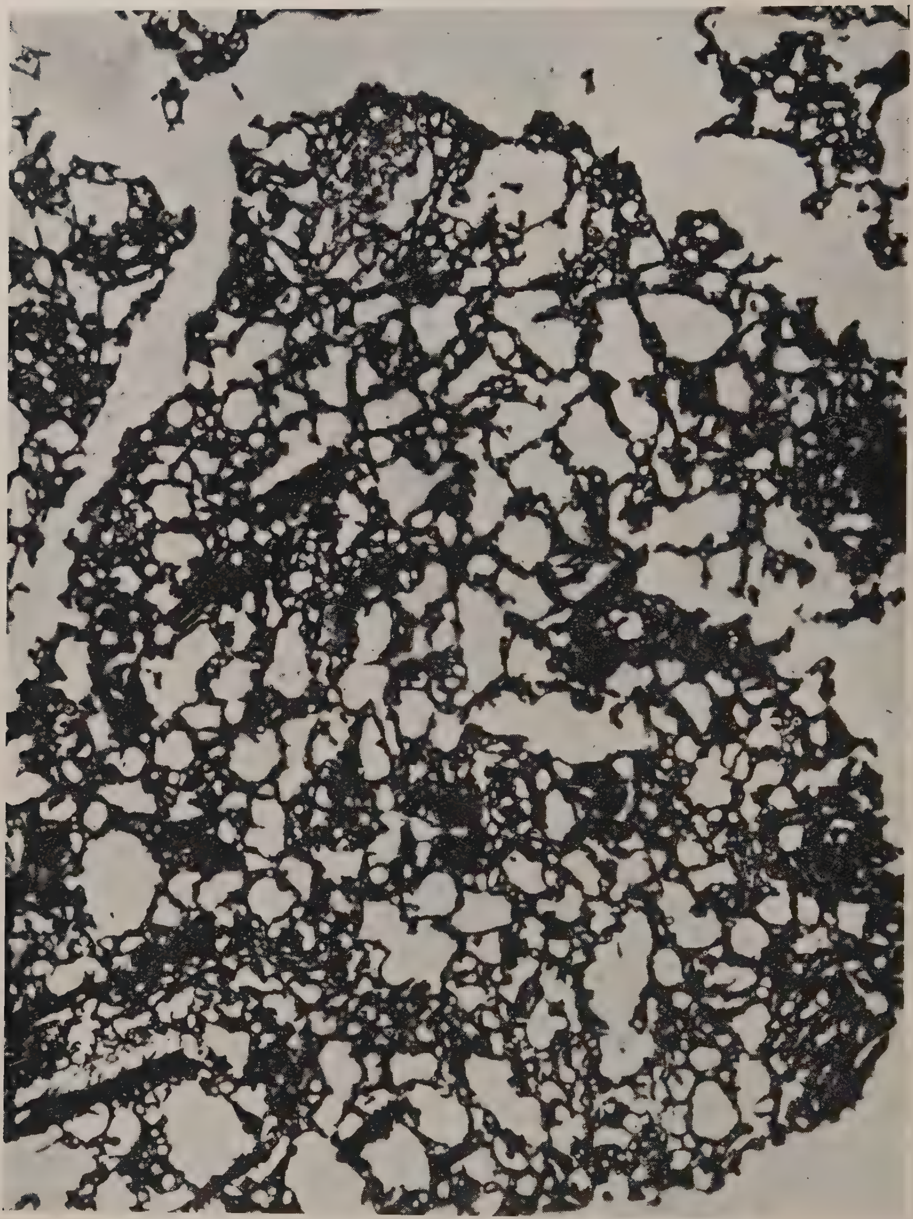


FIG. 17.—Micro-structure of Coke No. 3, S. Yorkshire (× 6).

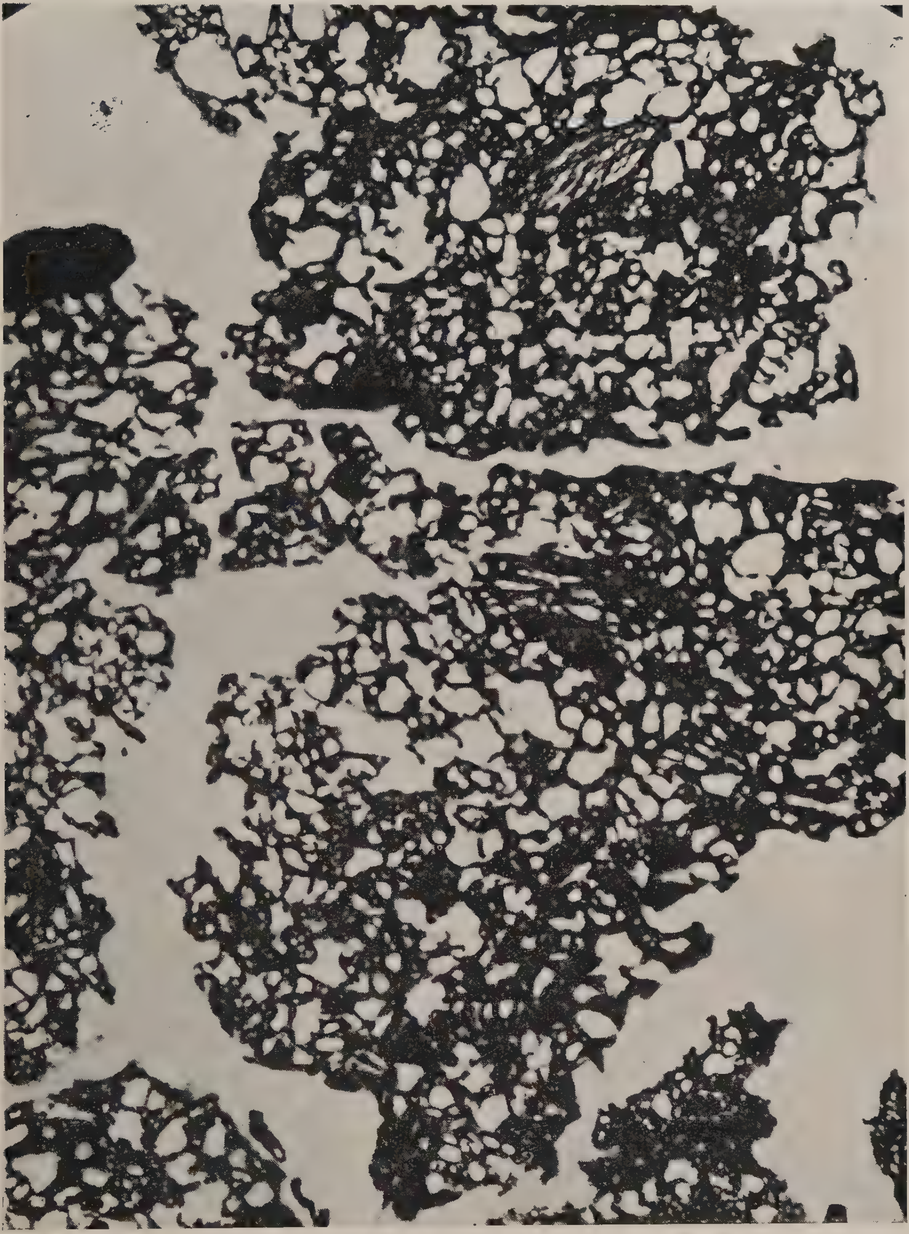


FIG. 18.—Micro-structure of Coke No. 4, S. Yorkshire (× 6).

Fig. 13 illustrates sections of typical pieces of coke made from the same coal (1) top-charged (coke No. 17A), and (2) (compressed) cake-charged (coke No. 17B), the conditions of coking being otherwise identical. The sections show why it is that, contrary to general belief, a coke made from top-charged coal is stronger than when the coal is compressed. Coke No. 17B is denser than No. 17A and would on that account be judged, by eye, to be the stronger; but the fractures in the former are more numerous and distinct and penetrate to the outside of the piece. The hardness of the two cokes as measured by the "shatter index" (1½-in. screen) showed: top-charged coal, 90; compressed coal, 82.

Fig. 14 represents sections of (1) a coke made from Sarre coking coal alone (coke No. 36A, "shatter index," 1½-in. screen, 75), and (2) a coke made from a blend of the same coal with 17 per cent. of low-temperature coke breeze (coke No. 36B, "shatter index," 1½-in. screen, 93). It will be seen that the coke made from the Sarre coal alone is much fissured, this being particularly evident in the transverse section. The coke made from the blend, however, is dense and but little fissured. Despite its hardness, as indicated by its "shatter index," examination of the section suggested that this coke would not be entirely satisfactory, but would be too dense and, possibly, brittle, the fissures appearing rather as cracks in a monolithic structure. Top-charging the blend, instead of the (compressed) cake-charging previously employed, was therefore adopted, and a marked improvement in the quality of the coke resulted.

The major fractures are fairly regular shrinkage cracks, but the presence in the coal of large pieces of shale may initiate irregular fracturing, the foreign bodies acting as nuclei for contraction. A layer of slurry in the coal may act similarly, and fractured surfaces of coke are sometimes seen to have a rough granular appearance due to inferior coke from imperfectly cleaned slurry.

Micro-structure

Study of the micro-structure of coke has but recently been begun by the Midland Coke Research Committee. As a first step, we are examining the coke sections already prepared for the study of their macro-structure under low magnification (5 to 10) with a binocular microscope, hoping thereby to obtain a general idea of the types of structures to be studied. The photomicrographs of Welsh, Durham and Yorkshire cokes reproduced in Figs. 15 to 18 show that marked differences exist in the pore structures of cokes dependent, presumably, on their origin. It is believed that a close study of these structures, upon which the combustibility of a coke and, perhaps, its hardness must in part depend, should form a useful adjunct to the more direct methods of coke research.

APPENDIX

The Preparation of Coke Sections by Rose's Method

A typical piece of coke, with complete cauliflower and centre-of-oven ends, is selected and photographed to obtain a front view and cauliflower-end view. The sectioning is then proceeded with as follows (see Plate XXII).

Moulding.—Place the specimen of coke on a piece of plate glass and build a mould round it with four pieces of wood, binding them together with cord. The mould should fit as closely as possible round the piece of coke. Remove the coke and scrub it with a stiff-bristled brush, under a jet of water, to remove all dust. Allow it to drain. Meanwhile, wipe the plate glass and smear it and the inside face of the mould with soft-soap solution. Now mix together plaster of Paris (superfine D) with 2 per cent. of calcined magnesia (light) in a porcelain basin, and add water as quickly as possible until a paste of the consistency of cream is obtained. Pour sufficient of this mixture into the mould to make an even layer about 1 in. thick. Quickly place the coke in the mould (Plate XXII, (1)), press it to the bottom and add more mixture until the coke is just evenly covered (2). This operation must be performed as quickly as possible, but care must be taken to ensure (by quick movement of the fingers in the mould) that the crevices of the coke are all filled in. The cast will become rigid in 10 to 15 minutes, during which time an "identification" number should be impressed on the rigid surface with a pointer. When the cast has become rigid, the wooden sides of the mould can be removed and the sides of the block scraped clean and washed with a jet of water. It is then placed on one side for several days to harden (3). The moulding operation takes about 45 minutes. The hardening period is desirable to prevent a partly dried cast from clogging the cutting wheel.

Cutting.—Draw pencil lines on the upper face of the block to indicate the position of the required cuts. One is usually made along the longitudinal axis and two at right angles to it so as to divide the block into six equal parts. The block is cut first longitudinally and then transversely by means of a carborundum wheel (12 in. × $\frac{1}{8}$-in. × $\frac{3}{4}$-in. hole 36/5E) * revolving on a horizontal axis at about 2000 r.p.m (4).

The cutting wheel is protected (like a circular saw) in a wooden casing with a slotted platform through which nearly half of it projects. The plaster block is guided along the wooden platform, care being taken to avoid any side thrust of the cut sides on the wheel. Since the wheel rotates towards the operator, it is advisable to have a movable wooden shield above the wheel (4) to deflect dust from his face. Goggles should be worn as an additional precaution. Dust-extracting equipment may be fitted if desired. No accident has occurred during the use of this method for about 150 cokes over a period of three years. Hand-controlled cutting has proved to be more satisfactory than a mechanically-operated totally enclosed system (the block being pulled by means of weights passing over pulleys), since the speed of cutting can be adjusted to suit the texture of the coke. With certain cokes any attempt to proceed too quickly causes the wheel to become hot and wear away rapidly. The time necessary for cutting varies with the size and "hardness" of the coke. An average specimen requires about 30 minutes. Loose pieces may fall from cokes that are much fractured; these should be carefully preserved and replaced later.

Cleaning.—During cutting, coke powder is forced into the pores of the coke. The dust must be carefully and completely removed by scrubbing the cut faces with a hard-bristled brush and a strong jet of water (5).

When clean, the cut faces are well rubbed over with a small quantity of freshly made plaster mixture (6), taking care to set any loose pieces of coke in their correct positions. This coat is allowed to set.

---

* Obtainable from Messrs. Burton, Griffiths and Co., Ltd., 64–70 Vauxhall Bridge Road, London, S.W. 1.

Grinding.—The cut faces are ground on sheets of plate glass (18 in. × 18 in. × $\frac{3}{8}$ in.) with carborundum powder and water (7). Each grade of powder is used with its own special plate. The grinding is carried out in three stages.

(1) After cutting, the surfaces of the coke are often found to be deeply scored and a coarse grade of powder (180 grade) is used until all score marks are removed and a plane surface is obtained.

It is worth noting that, unless plane surfaces at right angles to each other are obtained at this stage, either the resultant section will be poor, or unnecessarily hard and prolonged grinding will be unavoidable in the later stages. A plane surface cannot be obtained unless the surface of the coke is maintained flat on the glass plate. Since the plaster is softer than coke, it is necessary to apply less pressure to one side of a transverse section which includes more plaster than coke.

A circular motion is used during grinding. The ground faces are washed clean under a jet of water at frequent intervals to note the uniformity of the grinding. When the section surfaces are satisfactory they are carefully cleaned with a stiff-bristled brush under a jet of water, rubbed over with plaster mixture, and set on one side to dry.

The further stages enable the finer pores to be filled with plaster and a more uniform surface to be obtained.

(2) In the second stage, 280 grade (2F) carborundum powder is used.

(3) In the third stage, 60 min. (4F) carborundum powder is used and a soft-bristled brush is used for cleaning.

It has been found advisable to repeat the second and third stages at least twice to ensure the best results. In other words, each of the last two stages is interrupted in order to refill the pores with plaster, since in grinding down the coke the plaster tends to be dragged out of the pores. The mixture used for refilling in the last stage of grinding may be fine plaster of Paris alone, since any magnesia rubbed into the small pores would be dissolved out again by the water. Soft-bristled brushes are also used for cleaning the repeated second stage, and for the third stage, but for the repeated third stage only the fingers are used to avoid the removal of plaster from the smallest pores. The outer surfaces of the block may also be ground with 180 grade carborundum powder to give clean, smooth surfaces. After final rinsing, the block is set on one side to dry.

The average time taken for grinding, cleaning and refilling at each stage is as follows :—

Stage.	Grade of Powder.	Time (hr.).
1	180 grade	1 to 1½
2	280 grade (2F)	¾ to 1 (twice)
3	60 min. (4F)	¾ (twice)

Although the surfaces may be polished with still finer grades of powder, the procedure outlined has been found sufficient for visual examination of the fractures and the general pore development.

Photographing.—If the sections are to be photographed, the ground faces are first wetted to ensure a stronger black and white contrast. A longitudinal section and one face of the transverse section nearest the cauliflower end are usually chosen for photography. A perspective view of a finished block is given on Plate XXIII.

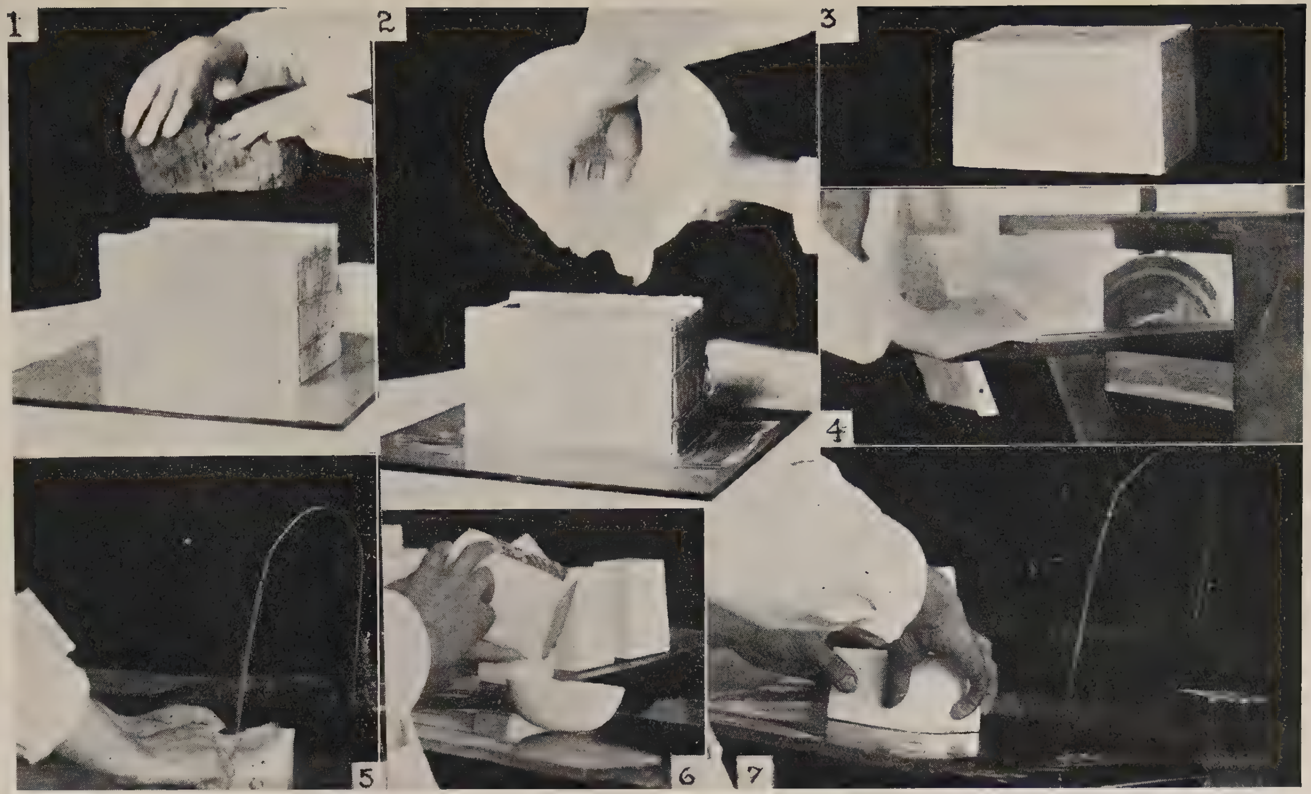


Plate XXII.—Method of Making Coke Sections.

1. Putting coke into mould.
2. Adding white composition.
3. Finished block.
4. Cutting block with a carborundum wheel.
5. Cleaning cut faces.
6. Rubbing white composition into cut faces.
7. Grinding cut faces.

[*To face p.* 54.

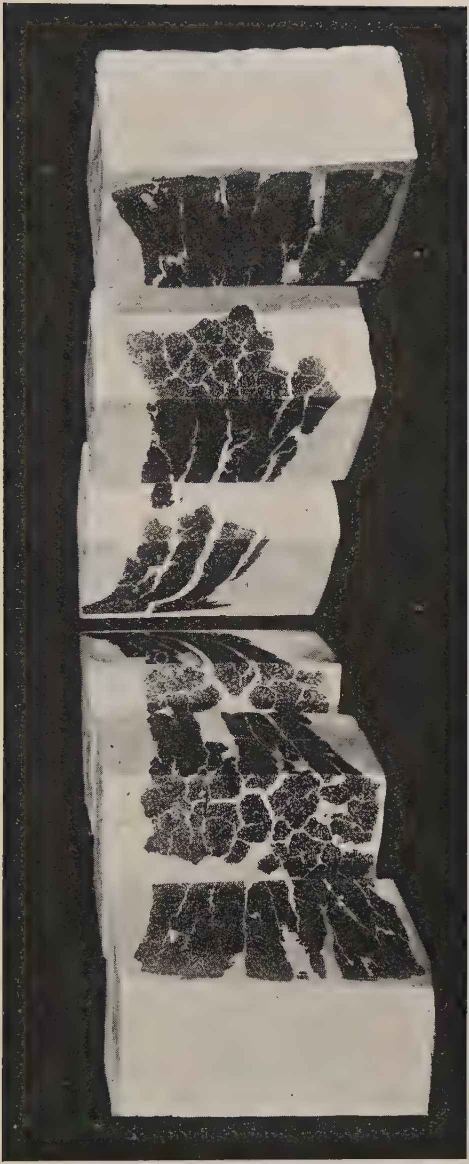


Plate XXIII.—View of Finished Coke Section.

[*To face p.* 54.

CHAPTER IV

THE ANALYSIS OF COKE

At the blast-furnace plant coke analyses are made both to check the quality of the deliveries and to determine to what extent the burdening of the furnace has to be varied to meet fluctuations in the carbon-content of the coke.

At the coke-oven plant the analyses are made solely to check the quality of the coke leaving the works.

General Considerations

Variations in the quality of coke deliveries at the blast furnace are found most frequently in the moisture- and ash-contents, particularly in the former, because of the effect of variable weather conditions and because of the difficulty sometimes experienced in standardising quenching operations at the ovens. The moisture content is usually determined, on a coarsely-crushed sample, as soon as each coke delivery has been sampled. The dried coke is then finely crushed for the determination of other constituents. Sometimes the " carbon-content " of the coke is calculated, by subtracting from 100 the sum of the moisture, ash, volatile matter and sulphur, as determined. Such a calculation gives only a rough approximation, because the coke contains nitrogen, hydrogen and oxygen (part of which is, however, expelled as " volatile matter ") as well as the constituents determined, whilst the percentages of those constituents are not all determined on the same basis. As an indication of the error introduced by this procedure, a coke with 5 per cent. of moisture containing, on the dried sample, 10 per cent. of ash and 1·5 per cent. each of volatile matter and sulphur, contains, as charged to the blast furnace, 17·3 per cent. of " impurities," not 18·0 per cent. as calculated.

At the coke-ovens, as at the blast furnaces, moisture is usually determined on the coarsely-crushed coke, and ash, volatile matter and sulphur on the finely powdered dried sample.

In our routine testing of coke samples, shatter, abrasion and combustibility tests are made before the cokes are sampled for analysis. This plan has been adopted for convenience, the breakage involved in these tests providing large quantities of graded coke from which representative samples can be taken for analysis. Considerable time has thus sometimes elapsed before the cokes have been finally sampled for analysis, and they have usually become " air-dried." Our estimations of moisture have therefore been made on the finely-ground samples used for the determinations of other constituents.

In this connexion mention should be made of preliminary tests undertaken to determine the best conditions for estimating moisture in lump coke. The percentage amounts of moisture in several cokes of ½- to 1-in. size, as determined in different ways, are recorded in Table XV.

TABLE XV.—THE DETERMINATION OF MOISTURE IN LUMP COKE (½- to 1-in.)

Coke.	No. 1 (S. Wales).		No. 2 (Durham).		No. 3 (S. Yorks.).		No. 4 (W. Yorks.).	
	a.	*b.*	*a.*	*b.*	*a.*	*b.*	*a.*	*b.*
(i) Heated for 1 hr. at 105° C. .	1·23	1·25	0·72	0·55	0·50	1·06	4·9	4·1
(ii) Heated for 2 hr. at 105° C. .	1·23	1·63	0·72	0·72	0·75	1·47	5·9	5·4
(iii) As in (ii) plus 1 hr. at 130° C. .	—	—	—	—	0·75	1·47	6·5	6·3
(iv) As in (iii) plus 16 hr. at 130° C. .	1·61	1·63	1·08	1·11	1·31	2·07	8·4	8·2

Heating for 1 hour at 105° C. (the standard procedure for finely-powdered coal) is thus seen to be insufficient to drive off all the moisture from lump coke, the error being greatest with cokes containing much moisture.

Tests of the same nature have been made on air-dried cokes ground to pass through a 60-mesh (I.M.M. standard) sieve, samples being heated at 105° C. during successive periods of 1 hour. The results are given in Table XVI.

TABLE XVI.—THE DETERMINATION OF MOISTURE IN GROUND AIR-DRIED COKE (THROUGH 60-MESH)

Coke.	No. 1 (S. Wales).	No. 2 (Durham).	No. 3 (S. Yorks.).	No. 4 (W. Yorks.)	No. 5 (Durham).	No. 6 (Durham).
Heated for 1 hr. at 105° C. .	0·51	0·39	0·37	2·10	0·49	0·74
Heated for 2 hr. at 105° C. .	0·66	0·49	0·40	2·17	0·49	0·75
Heated for 3 hr. at 105° C. .	0·73	0·55	—	—	0·49	0·75
Heated for 4 hr. at 105° C. .	—	—	—	—	0·53	0·75

The moisture-contents of air-dried cokes are low, rarely exceeding 0·5 per cent. It is noticeable that the coke (No. 4) which retained much moisture when in lump form also contained a high proportion when "air-dried" and finely ground. Coke No. 1 had unusually small pores and coke No. 2 an abnormal proportion of closed pores. Heating during 1 hour at 105° C. appears to give, in most instances, a sufficiently close approximation to the amount of moisture in finely-ground air-dried coke and we have adopted that procedure for all the cokes tested.

SAMPLING

The sampling of run-of-oven coke is not as a rule so difficult as is the sampling of run-of-mine coal, since the coke is made from finely-ground coal which has become well mixed during its passage through the washer and during crushing. Difficulties arise, however, when coals from different seams are not uniformly mixed before passing to the washer. For example, a number of wagons of slack from one seam may be tipped together, followed by a number from another seam. Another difficulty may be introduced by the uneven admixture with the coal charge of slurry, containing more ash than the usual washed smalls, though this uneven admixture provides "ballast" which does not appear in the blast-furnace coke.

When sampling coke at the bench for the determination of moisture, it should be remembered that, on an inclined bench, the coke in contact with the bench contains less water than that overlying it. Moreover, the outer portion of an individual piece of coke contains more water than the inner. For routine analysis at a coke-oven plant relatively small samples can be taken, for although each small daily sample may not be representative of the whole, a weekly average of the results will not deviate much from the analysis of an occasional large sample. For small daily samples the following method has been used.

The gross sample is taken at a time when the coke from, say, six ovens is lying on the bench. From each oven six pieces of coke are selected, three from the left-hand half and three from the right, and from each a portion about 1-in. cube is broken from the outside and another portion of about the same size from the inside. The three zones from which the six selected pieces are taken should represent the coke at about 2 ft. from the ram-side door, at the middle and at about 2 ft. from the discharge-side door of the oven. The pieces to right and left should be taken alternately from the over-lying and the under-lying coke. The gross sample of twelve 1-in. cubes of coke will be fairly representative of each oven.

Where mechanical handling is employed, pieces of coke may be collected for a number of ovens at convenient intervals from the belt conveyor.

For the work of the Midland Coke Research Committee, the method of dealing with the coke samples received at the laboratories has been as follows: After subjecting about 5 cwt. of the coke to size analysis, shatter and abrasion tests, sufficient was broken to 1- to 1½-in. size to provide 100 lb. for a furnace (combustibility) test, a quantity of ½- to 1-in. size being produced at the same time. This smaller-sized coke was quartered in the usual manner until about 100 grams had been obtained for pulverising.

PULVERISING COKE FOR ANALYSIS

When pulverising coke for analysis, care must be taken to avoid contaminating the sample with the materials of the grinding apparatus. The effect, on the ash-content of different cokes, of pulverising them to pass through a 60-mesh sieve with different appliances is illustrated in Table XVII.

TABLE XVII.—THE EFFECT ON ASH-CONTENTS OF DIFFERENT METHODS OF PULVERISING COKE

Method of Pulverising.	Cumberland Coke.		S. Wales Coke.		S. Yorkshire Coke.	
	Ash in Coke (per cent.).	Fe_2O_3 in Ash (per cent.).	Ash in Coke (per cent.).	Fe_2O_3 in Ash (per cent.).	Ash in Coke (per cent.).	Fe_2O_3 in Ash (per cent.).
Agate mortar and pestle . .	9·4	24·7	6·9	7·4	8·8	20·9
Manganese steel mortar and pestle . .	9·4	28·1	7·0	9·3	8·7	20·3
Wedgewood mortar and pestle (mechanical) .	9·8	22·5	7·5	11·3	9·2	20·5
Wedgewood mortar and pestle (hand) . .	—	—	7·2	—	9·3	—
Iron mill . .	11·5	37·8	7·7	14·6	9·9	32·3
Iron bucking board . .	11·9	36·9	8·1	20·3	13·3	46·8

There is least contamination from an agate mortar, whilst grinding in an iron mill or rubbing on an iron bucking board causes a considerable addition of iron to the ash. Grinding in a Wedgewood mortar causes an addition of siliceous matter. The most satisfactory alternative to grinding in an agate mortar, a laborious process, is stamping in a manganese-steel mortar (Fig. 19). Care must be taken, however, not to introduce any grinding action if a manganese steel mortar is used, as appears from the results recorded in Table XVIII.

TABLE XVIII.—THE EFFECT ON THE ASH-CONTENTS OF COKE OF GRINDING AND OF STAMPING DURING PULVERISATION

	S. Wales Coke. Ash (per cent.).	S. Yorkshire Coke. Ash (per cent.).
Ground in agate mortar	6·9	8·8
Ground in manganese-steel mortar .	7·3	9·0
Stamped in manganese-steel mortar .	7·0	8·7

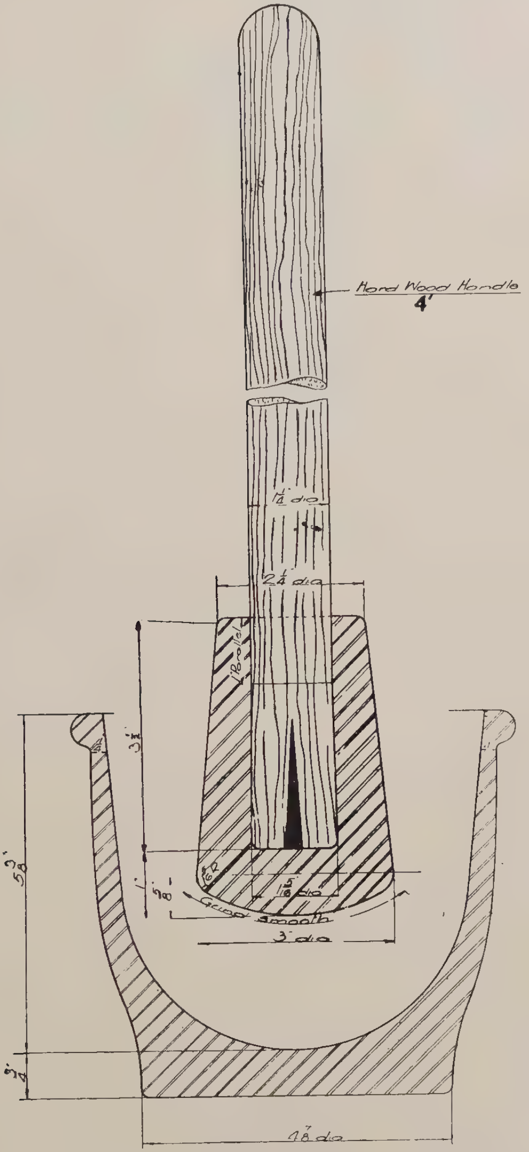

Hard Wood Handle
4'
1¼" dia
2¼" dia
1" Parallel
3½"
1/16 R
5/8"
1 5/16" dia
Grind smooth
3" dia
5⅜"
¾"
1⅞" dia

Fig. 19.—Six-inch Era Manganese-steel Mortar and Pestle for Pulverising Coke.

The manner of using the manganese steel mortar is as follows: A small charge of the coke is broken to about $\frac{1}{16}$-in. size by light blows with the pestle (which is fitted with a 4-ft. wooden handle), the mortar standing on the floor. It is then pulverised by about fifty blows from a height of about 18 in. and screened through a 60-mesh sieve, the over-size being returned to the mortar with a fresh charge of coke. If small charges are used, there is not much loss of coke during treatment and 100 grams of through 60-mesh size can be prepared in about 20 minutes.*

ANALYSIS

All analyses are made on air-dried coke pulverised to pass through a 60-mesh (I.M.M. standard) sieve.

Moisture.—From 1 to 5 grams of the pulverised coke are heated in a shallow silica dish during 1 hour at 105° C. and the loss in weight is determined after cooling in a desiccator. The silica dish has an aluminium cover (removed during the heating) to guard against the absorption of moisture during the final weighing.

Ash.—From 1 to 5 grams of the pulverised coke are incinerated in a shallow silica dish in a muffle at about 800° C. until on lightly tapping the dish, or stirring the contents, no black particles can be seen. When carrying out a number of determinations it is convenient to add 5 grams of coke to a dish of known weight. After incineration and cooling in a desiccator, the dish containing the ash can be weighed to the nearest milligram, the ash swept out with a camel-hair brush and the dish alone then weighed. The weight of the charge of coke used need be accurate only within 5 milligrams.

Volatile Matter.—Methods used for determining the "volatile matter" of coal are not suitable for coke, for it evolves insufficient gases on heating to maintain a reducing atmosphere within the crucible. Oxidation of the coke may therefore occur, the estimated quantity of volatile matter being, in consequence, too high. In some laboratories the crucible used for the determination is placed within a larger one, the space between the two being packed with small pieces of coke. Heating during 30 minutes may be necessary to drive off all the volatile matter. Apart from this inconvenience, the method is liable to error due to oxidation of the coke by the air originally in the crucible. The addition of a few drops of benzene obviates this.

For routine purpose, our present method is as follows: One gram of coke is weighed into a silica crucible fitted with lid and a few drops of benzene are added. The crucible is placed with others on a tray of special design (see Beet, *Fuel*, 1925, **4**, 382) which is introduced into an electrically heated muffle furnace with a plug door. The initial temperature of the muffle is 920° C. The temperature drops on insertion of the tray of crucibles, but rises to about 900° C. at the end of 7 minutes, when the crucibles are withdrawn, cooled in a desiccator and weighed.

---

* See also "The Grinding of Coke for Analysis," by J. Hiles and R. A. Mott, *Fuel*, 1928, **7**, 509.

Sulphur.—Eschka's method is used. One gram of coke is mixed with 3 grams of Eschka's mixture (2 parts pure light calcined magnesium oxide with 1 part pure anhydrous sodium carbonate), charged into a shallow silica dish and covered with a further 1 gram of Eschka's mixture. The dish is heated in an electric muffle at a dull red heat, with frequent stirring, until black particles have disappeared. After cooling, the contents of the dish are washed into a beaker with hot water and digested with bromine water (to oxidise sulphites to sulphates). Excess of hydrochloric acid is added to dissolve solids and the liquid is then boiled to expel bromine and filtered. To the boiling filtrate 1 to 2 grams of ammonium chloride and 10 c.c. of a 10 per cent. barium chloride solution are added. Gentle boiling is continued for a short time and the precipitate then allowed to settle. The addition of ammonium chloride flocculates the precipitate of barium sulphate and renders early filtration possible. When the precipitate has settled, it is collected by decantation, filtration and washing with hot water on a filter-paper, washed until free from chlorides, dried, ignited and weighed. A blank determination is carried out under the same conditions.

Nitrogen.—The Midland Coke Research Committee has, as yet, paid but little attention to the determination of nitrogen in coke, for it is of little practical importance. In collaboration with the Department of Fuel Technology of Sheffield University, a study has been made of the application to coke samples of the standard method of determining nitrogen in coal. Duplicate samples have been sent to Professor ter Meulen, of Delft, Holland, for examination by the new method of analysis for nitrogen that he has devised. This has been found the most satisfactory for coke. Details of these tests will be published later in the technical press.

Phosphorus.—We have made no determinations of phosphorus in coke, because in the coke-producing area covered by the Midland Coke Research Committee the amount of phosphorus that a coke may contain is, in general, of little importance.

Several methods are in use. Whilst none is entirely satisfactory, we understand that the most reliable, which we include for general information, is the following.*

Weigh 1 gram of the finely-ground ash of the coke in a platinum crucible, add 10 c.c. of concentrated nitric acid and 10 c.c. of hydrofluoric acid. Evaporate the solution to dryness, add 5 c.c. of concentrated nitric acid and again evaporate to dryness. Carefully ignite the crucible and contents over a quiet Bunsen flame and fuse the residue with 5 grams of pure sodium carbonate. Digest the contents of the crucible in a 6-in. porcelain basin with 50 c.c. of hot distilled water at 90 to 95° C. (occasionally bruising the cake with a glass rod) until the melt is completely disintegrated into a fine powder free from lumps, filter, wash with 2 to 5 per cent. sodium carbonate solution, ignite the residue and fuse with a further 3 grams of sodium carbonate. Repeat the leaching, filter and wash well with sodium carbonate solution, then add gradually, in order to avoid violent effervescence, an excess of concentrated nitric acid to the combined filtrates. Evaporate to a bulk of about 50 c.c.

---

* See "Methods of Analysis of Coal," Fuel Research Survey Paper No. 7, H.M. Stationery Office, London, 1927.

To the 50 c.c. of solution in a beaker add 30 c.c. of nitric acid (sp. g. 1·2) and 5 c.c. of ammonium hydroxide. Allow the solution to cool to 60 to 65° C., then run in, in a thin stream, 30 c.c. of nitro-molybdate solution * (previously heated to 60 to 65° C.), into the middle of the beaker, which is continuously rotated during the addition and during 2 minutes thereafter. After an interval of 30 minutes, filter through paper-pulp in a Gooch crucible, wash with 0·1 per cent. solution of potassium nitrate in quantities of 10 to 20 c.c. until 5 to 10 c.c. of the washings mixed with $\frac{1}{2}$ c.c. of phenolphthalein solution become strongly coloured when 1 drop of $N/25$-sodium hydroxide solution is added. Transfer the paper-pulp and precipitate to the original beaker, which has also been washed free from acid, add n_1 c.c. of $N/25$-sodium hydroxide solution, using a portion of this to rinse out the crucible, wash the crucible with 50 c.c. of previously boiled, hot distilled water, then digest the contents of the beaker until the yellow precipitate has dissolved to a colourless solution. Titrate the excess of sodium hydroxide with $N/25$-nitric acid (n_2 c.c.), using phenolphthalein as indicator. The weight of phosphorus is $0{\cdot}000054\ (n_1 - n_2)$ gram.

Arsenic.—The determination of arsenic in coke is of importance if it is to be used for drying malt. A modified Gutzeit method of analysis is generally used, one due to Allen and Palmer, further modified by Scott, being given by the latter in his book " Standard Methods of Chemical Analysis," New York, 1927. This book should be consulted for details.

Carbon.—Although usually calculated roughly by difference, the carbon-content of a coke can readily be determined directly by the standard method of combustion analysis used for organic compounds, in which a weighed quantity of the material is burned in a stream of oxygen and the products are passed through heated columns of copper oxide and lead chromate, the carbon dioxide formed being absorbed by potassium hydroxide solution.†

It is of interest to compare figures obtained directly in this way with those calculated by subtracting the sum of the moisture, ash, volatile matter and sulphur in the coke from 100. This has been done in Table XIX.

---

* 150 Grams of ammonium molybdate in 1 litre of water added to 1 litre of 5N-nitric acid.

† For details, Fuel Research Survey Paper No. 7 (*loc. cit.*) should be consulted.

TABLE XIX.—COMPARISON OF CARBON-CONTENTS OF COKES AS DETERMINED DIRECTLY AND AS CALCULATED

Proximate Analyses. (Per cent. on Coke as Received.)

	Coke No. 1.	Coke No. 2.	Coke No. 3.	Coke No. 4.
Moisture	1·26	1·33	1·54	9·42
Ash	8·43	8·98	12·22	10·71
Volatile matter	0·38	0·71	0·16	1·56
"Fixed carbon" (by difference)	89·93	88·98	86·08	78·31

Ultimate Analyses. (Per cent. on Coke as Received.)

	Coke No. 1.	Coke No. 2.	Coke No. 3.	Coke No. 4.
Carbon	87·54	87·32	83·26	75·97
Hydrogen	0·91	0·75	0·17	0·60
Nitrogen	1·18	1·26	1·14	1·27
Sulphur	0·91	0·61	1·55	1·24
Ash	8·43	8·98	12·22	10·71
Moisture	1·26	1·33	1·54	9·42
Oxygen (by difference)	—	—	0·12	0·79
	100·23	100·25	100·00	100·00

	Coke No. 1.	Coke No. 2.	Coke No. 3.	Coke No. 4.
Carbon determined	87·54	87·32	83·26	75·97
Carbon calculated (from "Fixed carbon" less sulphur)	89·02	88·31	84·53	77·07
Error	+1·48	+0·99	+1·27	+1·10

The carbon-content of a coke calculated in this way may thus be from 1 to 1½ per cent. too high, due mainly to omission to take account of the nitrogen-content.

On the other hand, the common practice of determining the ash, sulphur and volatile matter on the dry coke and adding the sum of these to its moisture-content produces a positive error in the estimate of "total impurities" and therefore a negative error in the estimate of "carbon." The error is — 0·7 per cent. when the coke contains 5 per cent. of moisture and — 1·3 per cent. when it contains 10 per cent. This error may therefore sometimes cancel the error of calculation of carbon from a normal proximate analysis.

CHAPTER V

THE REAL, APPARENT AND BULK DENSITY OF COKE AND ITS POROSITY

Determinations of the real and apparent densities of a coke have probably in the past been the most widely-used tests, other than chemical analyses, of its quality. On the other hand, experimenters have had little or no guidance as to the significance to be attached to the values obtained. Usually they have been reported without comment save for calculation from them of the total pore space of the coke. It has not been made clear whether a high figure for the " total porosity " of a coke was desired or whether a dense, close-grained coke was sought.

In view of this uncertainty as to their value, it is perhaps not surprising that attempts to standardise the tests have been somewhat half-hearted. A considerable amount of work on the subject has, however, been done, some of the more important of which must be outlined.

Fulton, an American blast-furnace superintendent, appears to have been amongst the first to study the porosity of coke (*Trans. Amer. Inst. Min. Eng.*, 1883; see also " Coke," by Fulton. Scranton, 1905). His method was to crush a cubic inch of coke, determining the weight of the coke substance and its specific gravity and calculating from these data the percentage of cell space in the cube. Fulton made a number of such determinations for American beehive cokes and cokes made from the same coals in the, at that time, recently introduced by-product ovens, his general conclusion being that the percentage cell-space in the beehive coke was about 55, as compared with 30 to 50 for the by-product coke. On the general question of the cell-space of blast-furnace fuels, some comparative figures of Fulton's (Table XX) for the working of blast furnaces are of interest.

Table XX.—Comparison of Different Blast-furnace Fuels (Fulton, 1905)

Fuel.	Size of Furnace. Ft.	Pig Produced per Month.	Fuel per Ton of Pig (lb.).
Charcoal	12 × 60	3,379	1815
Anthracite	17 × 65	2,698	2244
Anthracite and coke .	15½ × 55½	2,565	2200
Beehive coke . . .	22 × 90	12,000	1800

Fulton considered that the difference observable in the monthly output of pig when using coke as compared with anthracite was indicative of the "relative calorific energies" of the two fuels, which could not be explained by differences in chemical composition and must therefore be due to differences in physical structure. The anthracite, being non-porous, was less "energetic" (*i.e.* less reactive). A well-developed cell-structure in a coke was therefore desirable.

Thörner (*Stahl u. Eisen*, 1886, **6**, 71) assumed that the more nearly the cell-structure of a coke approached that of wood charcoal the greater its value in a blast furnace. The percentage pore space of wood charcoal, according to his determinations, varied between 56 and 76 and the cells formed series of long, open-ended tubes. "Meiler" coke, of good value in the blast furnace, had only 30 per cent. pore space, but the structure was regular. Oven coke had an irregular porous structure and was mostly fused together as a dense vitreous mass. From tests made with Bell's method for determining the "reactivity" of fuels with carbon dioxide, Thörner concluded that the fuels most highly prized for blast-furnace use, namely wood charcoal and "meiler" coke, had markedly greater reactivity than oven coke at high temperatures.

Anderson (*J. Soc. Chem. Ind.*, 1896, **15**, 20) devised a method for determining the real density of coke, grinding it to the size of fine sand and weighing it in a tared specific gravity bottle. The fine coke, covered with water, was heated at 90 to 100° C., the neck of the bottle being connected to a water-pump. Exhaustion was continued during 2½ hours. The bottle was then detached from the pump and filled with cold water, dried and weighed. The difference between the weight of water required to fill the bottle with and without the coke gave the water equivalent of the volume of coke used. This weight divided by the weight of the coke gave its real density,

Anderson also described an apparatus of small volume (50 c.c.) for the determination of apparent density, small pieces of coke being introduced into water and the volume displacement noted. The percentage porosity of the coke could then be determined by dividing the difference between the real and apparent densities by the real density and multiplying by 100. These methods of Anderson's have been widely used.

Ramsberg and Sperr (*Trans. Amer. Inst. Mech. Eng.*, 1917, **39**, 897), from an examination of a number of American cokes, deduced that no connexion existed between the average size of their pores, as judged visually from longitudinal sections, and their percentage porosity. Grading the cokes in order of increasing size of pores, in terms of four standards, the corresponding percentage porosities were as recorded in Table XXI.

On these results, Ramsberg and Sperr regarded the determination of the percentage porosity of coke as valueless unless it were supplemented by observations as to the size of the pores and the thickness of the pore-walls.

Malleis (*Ind. Eng. Chem.*, 1924, **16**, 901) extended Ramsberg and Sperr's observations with an examination of twenty cokes of which the apparent density ranged between 0·75 and 1·24 (the upper

TABLE XXI.—COMPARISON OF CELL SIZE OF COKES AND THEIR PERCENTAGE POROSITIES (Ramsberg and Sperr, 1917)

Cell Grade.	Apparent Density of Coke.	Real Density of Coke.	Percentage Porosity
1 (standard)	1·10	1·92	42·8
1	0·92	2·01	53·7
1·5	0·97	1·89	48·5
2 (standard)	1·01	2·03	50·4
2	1·14	1·95	41·6
2·5	0·86	1·98	56·7
3 (standard)	1·07	1·83	41·6
3	1·05	1·92	45·1
3	0·85	1·86	54·1
4 (standard)	0·94	1·99	52·6
4	0·94	1·99	52·6
4	0·92	1·92	52·3

limit for nineteen of them being 1·10), the real density between 1·79 and 2·02, and the percentage porosity between 38·6 and 58·6. Sometimes there appeared to be agreement between the porous structure of the cokes, as determined from sections, and the percentage porosity, for example, with dense cokes of low porosity, but with others there was no agreement. An apparently dense coke might have a high porosity because the pores were small and the pore-walls thin. In this connexion, Malleis suggested the following classification: (1) Very small cells, with very thin cell-walls; (2) large cells, with thin cell-walls; (3) small to medium cells with fairly thick cell-walls; and (4) large cells with fairly thick cell walls. The cell-walls of class 4 were often observed to contain small pores.

Rose (*Ind. Eng. Chem.*, 1922, **14**, 1047) obtained information as to the effect, on the real density of coke, of fine grinding, using benzene as the wetting liquid. His average results can be summarised as follows :—

Size of Coke.	Average Real Density.
1. Through 60-mesh (28 per cent. through 200)	1·69
2. ,, 60-mesh (64 per cent. through 200)	1·70
3. ,, 200-mesh	1·73
4. ,, 200-mesh (24 hr. further grinding of (3))	1·73

When using different wetting liquids, Rose obtained the following figures for the same coke sample :—

Wetting Liquid	Real Density
Water	1·85
Benzene	1·75
Carbon tetrachloride	1·84
Carbon bisulphide	1·88

His final conclusion was that boiling in water during ½ hour appeared to be as satisfactory a treatment as any. As regards fine-grinding of the coke, although Rose recommended grinding through 200 mesh, there does not appear to be sufficient difference between the results obtained with such fine dust and with through 60-mesh coke to warrant undertaking the difficult task entailed in grinding coke through 200-mesh.

Sutcliffe and Evans (*J. Soc. Chem. Ind.*, 1922, **41,** 196T) made a study, under laboratory conditions and with a hand-fired boiler, of materials of different "combustibility" (rate of reaction with oxygen). Raw coal, pitch-blended briquettes and briquettes made without a binder under a pressure of 10 tons per sq. in., were found to be of increasing combustibility in the order named, and it appeared that the high combustibility of the briquettes was due to their finely porous structure. Sutcliffe and Evans argued that the combustibility of a fuel was primarily dependent on the total area of surface exposed to the air, and that this, in turn, was dependent, not on its total porosity, but on the number of pores and the manner in which they were inter-connected. They considered that the microscopic pores, of diameter less than 1×10^{-3} cm., were the most important, and that the most combustible fuel should be dense, with many such fine pores per unit mass.

METHODS OF DETERMINING DENSITY AND POROSITY

Before discussing our experience of the significance of porosity in blast-furnace coke, the methods used for determining it must be described.

Apparent Density.—At the outset we used a modification of the "Tentative method of test for volume of cell space of lump coke" proposed by the American Society for Testing Materials (Serial D 167–23T, 1923). In this method several pieces of coke are weighed in air and then immersed (held in a wire cage) in a rectangular tank filled with water to an overflow level. The volume of water displaced by the coke, less that absorbed by it, is regarded as its volume. This is clearly a more reliable method than Anderson's (*q.v.*) by reason of the scale of operations, but we considered that it would be more satisfactory still to use several full-length pieces of coke, so as to make allowance for the known differences in porosity exhibited by the cauliflower and centre-of-oven ends.

A rectangular zinc bath, 14 × 10 × 9 in. deep, fitted with a ⅜-in. overflow pipe 1 in. from the top, was filled with water until it overflowed to constant level, and the overflow pipe (slightly greased to prevent prolonged dripping) was then closed. A full-length piece of coke, dried to constant weight on a hot-plate, was placed in a 1-in. mesh wire cage (having a wire lid) and lowered into the bath (see Fig. 20). The coke was immersed during 15 minutes, with occasional shaking to dislodge air-bubbles and allow the water to percolate into the major fractures. The overflow stopper was then removed and the water displaced by the coke collected and weighed.

On raising the wire cage, the coke was allowed to drain within it during 1 minute and was then weighed. The weight of overflow water, less that retained by the coke, divided by the weight of the dry coke, gave the apparent density of the coke. Three or more determinations are made and the mean result is accepted.

Such a method is simpler, and therefore preferable, to any involving the use of a coating of paraffin wax on the coke, to prevent the penetration of water, or employing immersion liquids of high surface tension, such as mercury or glycerine, for the amount of water absorbed by a full-length piece of coke is small and is allowed for in the calculation.

The Northern Coke Research Committee have improved on this method (see Braunholtz, Nave and Briscoe, *Fuel*, 1928, **7**, 110) by introducing means for determining the percentage of open pores in the coke (*i.e.*, pores communicating readily with the outer air). If a lump of coke is completely immersed in boiling water during 30 minutes and allowed to cool to room temperature in the water, the amount of water entering the pores of the coke (which, expressed on the volume of the coke, gives the percentage of open pores) is the same as when the pressure above the surface is alternately reduced and allowed to return to atmospheric. The following procedure has now been adopted.

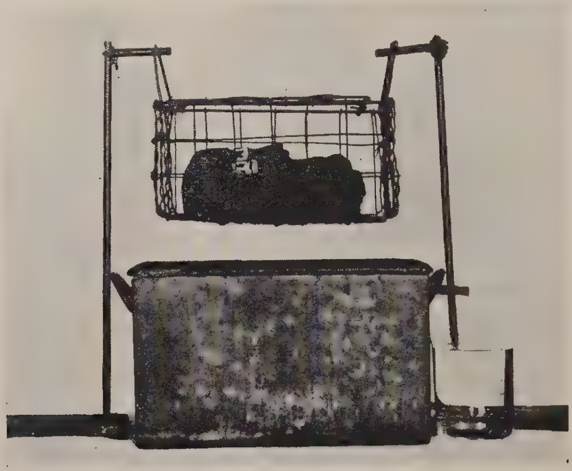


FIG. 20.—Earlier Apparatus for the Determination of the Apparent Specific Gravity of Coke.

Full-length pieces of coke are dried to constant weight (w_1). The pieces are immersed in boiling water during $\frac{1}{2}$-hour, in a bath such as that already described, and then quickly transferred to a large tank of cold water. When cooled, the coke is weighed, from the beam of a suitable balance, within the water (w_2). It is then removed, drained and weighed again (w_3).

If the coke were solid, the weight of an equivalent volume of water would be $w_1 - w_2$. Since water has entered the open pores, however, the weight of the coke in water (w_2) must be reduced by the amount of water adsorbed ($w_3 - w_1$). The equivalent volume weight is therefore $w_1 - \{w_2 - (w_3 - w_1)\} = w_3 - w_2$.

The apparent density is : $\dfrac{w_1}{w_3 - w_2}$.

$$\text{The percentage apparent porosity} = \frac{\text{Volume of open pores}}{\text{Volume of coke}} \times 100$$

$$= \frac{w_3 - w_1}{w_3 - w_2} . 100.$$

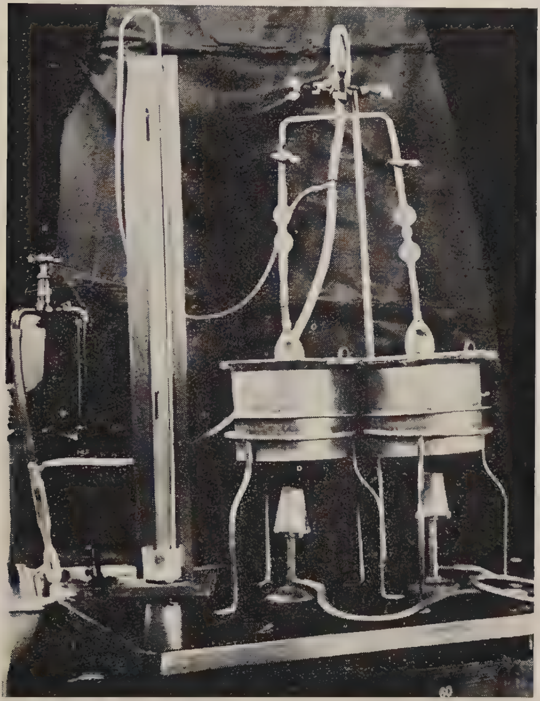


FIG. 21.—Apparatus for the Determination of the Real Specific Gravity of Coke.

Real Density.—Our method of determining the real density of coke is that described by Greenwood and Cobb (*J. Soc. Chem. Ind.*, 1922, **41**, 181T), which is a modification of Anderson's (*q.v.*). The apparatus used is illustrated in Fig. 21. A specific gravity bottle is cleaned with alcohol, dried, filled with distilled water and immersed in a constant-temperature bath at a convenient laboratory temperature, say 15° C., during 1 hour. The bottle is then weighed (w_1). After emptying out the water, the neck of the bottle is dried and 2 grams of coke ground to pass a 60-mesh sieve (I.M.M. standard) are introduced together with distilled water sufficient to half fill the bottle. The perforated stopper is then inserted and connected, by rubber pressure tubing, to a suction-pump and manometer. A splash-bulb is introduced above the stopper (as in Fig. 21) and the bottle rests on a water-bath. The pressure within the bottle is reduced to 30 cm. mercury, to allow of the water being gently boiled during 1 hour. A clip above the splash-bulb is then closed, suction stopped and the clip reopened. Any water that has collected in the splash-bulb will run back into the bottle, carrying any coke particles with it. The bottle is then shaken, to cause any scum of fine particles of coke to sink, allowed to stand during 1 hour in the constant-temperature bath, completely filled with water at the same temperature and weighed (w_2). The water displaced by the coke is $(2{\cdot}0000 + w_1) - w_2$, and the real density of the coke is :

$$\frac{2{\cdot}0000}{2{\cdot}0000 + w_1 - w_2}.$$

If the temperature of the bath is not constant, a correction of 0·01 should be added for each 1° C. rise in temperature.

Total Porosity.—The total porosity of a lump of coke is the total volume of pore space divided by the volume of the lump, or :

$$\frac{(\text{Volume of coke}) - (\text{Volume of cell walls})}{(\text{Volume of coke})}$$

$$= 1 - \frac{(\text{Volume of cell walls})}{(\text{Volume of coke})}$$

$$= 1 - \frac{(\text{Weight of coke}) \times (\text{Volume of cell walls})}{(\text{Volume of coke}) \times (\text{Weight of coke})}.$$

Since the weight of the "coke" is the weight of the cell walls, this expression becomes :

$$1 - \frac{(\text{Apparent density})}{(\text{Real density})},$$

or,

$$\frac{(\text{Real density}) - (\text{Apparent density})}{(\text{Real density})}.$$

The percentage porosity is estimated by multiplying by 100.

Bulk Density.—The bulk density of most significance is the volume of 1 cu. ft. of coke within the blast furnace after it has suffered all the breakage due to handling and charging. The "shatter test" (*q.v.*) provides suitable material.

In our earlier tests, a cubical box of 1 ft. side (internal) was used and from the 50 lb. of coke from a shatter test, after mixing and quartering, 25-lb. charges from opposite quarters were used for the determination of volume.

The Northern Coke Research Committee (see *Fuel*, 1929, **8**, 418) have used a cubical box of 1 ft. $3\frac{1}{8}$ in. side, having a capacity of 2 cu. ft., which would receive all the coke from one shatter test.

They have compared this measure with a cylindrical one and with a standard hectolitre, and recommend that it should be adopted as standard. The test is admittedly a rough one. Check determinations usually agree within 1 lb. of coke per cu. ft.

In carrying out the test in this way, as we now do for the sake of uniformity in the work of the several committees, the 50 lb. of coke from a shatter test is shovelled indiscriminately into the box, which is then shaken several times. The volume of the coke is then read from calibrations on the inside of the box. In parallel tests which we have made, determining the weight of coke required to fill boxes 1 ft. and 1 yard cube, the differences in the results were not important enough to warrant undertaking, as a routine, the considerably greater labour necessary to determine the weight (about 8 cwt.) of a cubic yard of coke, though such a determination is presumably more accurate than the alternative we have adopted, *i.e.* measuring the volume of 50 lb. of coke.

General Considerations

The significance, if any, of porosity in blast-furnace coke has been judged mainly by analogy with such fuels as wood charcoal, "meiler" coke, anthracite and beehive coke, the behaviour of these fuels suggesting that a "well-developed porous structure," with inter-connected open pores, is desirable in a blast-furnace coke. On general grounds, apart from blast-furnace practice, it has been suggested that microscopic pores were of greater significance than megascopic.

In the absence, at present, of any method for determining the specific pore surface of a coke,* it is not possible to debate satisfactorily the importance or otherwise of the factors suggested. We have, however, obtained some information on the subject by the use of certain "combustibility" tests. The method of test, which is fully described in a later chapter, involves burning coke of 1- to 1½-in. sizes with a blast of air in a furnace of 1 sq. ft. grate area at a rate of about 40 lb. per sq. ft. of grate area per hour. The chief significant data recorded are: the distance above the grate at which all the oxygen of the air-blast is consumed; the rate of reduction (in a fuel-bed 12 in. deep) of the carbon dioxide formed; and the temperature attained on combustion at different levels in the fuel-bed. The observations, other than statistical, that follow are mainly based on such tests.

Apparent Density.—The apparent density of Yorkshire cokes made from top-charged coal is usually less than 0·90. Strongly caking (and swelling) Yorkshire coals, when rapidly coked (as in 14-in. ovens), may yield cokes with as low an apparent density as 0·75. Of such Welsh cokes as we have examined, the apparent density has been about 0·90 and that of Durham cokes has been rather higher. Cokes made from compressed charges usually have an apparent density greater than 0·90 and often greater than 1·0, the highest figure for a coke made from a straight coal (Durham, No. 5) being 1·12. The average value for a coke made from a compressed blend of a Welsh coking coal and anthracite duff was 1·14, the value for some pieces being 1·43.

---

* A method for making this determination is now under consideration.

Real Density.—The real density varies between 1·8 and 2·0.

Percentage Apparent Porosity.—In general, about 80 per cent. of the coke pores are " open " and a common value for the percentage apparent porosity is 40.

True (Total) Porosity.—Variations between 36 and 59 per cent. have been noted for the true porosity.

The Effect of Porosity on the Hardness of Coke.—Our general experience has been that " compressed " cokes with an apparent density exceeding 1·0 are brittle. Denseness of a coke may therefore reduce its hardness. On the other hand, cokes having many enlarged pores, with an irregular pore structure, have been of a low degree of hardness. These have been made from poorly-caking coals (*e.g.*, coke No. 17E, total porosity 58 per cent., apparent porosity 47·7 per cent.). It can be said, in general, that for hardness a coke should not be so dense as to be brittle nor so porous, with enlarged pores, as to be soft.

The Effect of Porosity on the Combustibility of Coke.—With cokes of suitable hardness, a high percentage porosity (provided that the pores are not enlarged) appears to be associated with an ability to develop high temperatures on combustion (under the conditions of our tests). The highest temperatures of combustion have been reached with cokes having between 54 and 58 per cent. total porosity. That the total porosity should be of more importance in this connexion than the apparent porosity is no doubt due to the fact that the closed pores become opened during combustion.

Cokes made from blends of Welsh coking coal and anthracite which, as already mentioned, tend to be dense and brittle, also develop high temperatures during our combustibility tests, despite the fact that their total porosity is only about 40 per cent. The pores of such cokes are small and numerous, so that the total pore surface, the factor presumed to be of real significance, is high.

The effect of the porous structure of cokes on their reactivity towards oxygen and carbon dioxide is discussed fully in a later chapter, but it may be here stated that highly reactive cokes have frequently been found amongst those of either abnormally low or abnormally high apparent and total porosities.

In general, it may be said that, for cokes made from a straight coking coal, a high percentage total porosity (54 to 58), provided that the structure is fairly uniform and there are not many abnormally large pores, is desirable for blast-furnace work, inasmuch as they appear to have the ability to generate high temperatures on combustion.

CHAPTER VI

THE ABRADABILITY OF COKE

NUMEROUS tests have been devised to measure the so-called "hardness" of coke. Most of them are "tumbler" or "drum" tests, in which a specified weight of the coke is rotated within a drum during a given time and measurement then made of the percentage of breeze formed. This percentage has been given some such term as "index of hardness."

As previously explained (p. 16), the measure thus obtained is related both to the "surface hardness" (abrasion hardness) and the "impact hardness" (true hardness) of the coke, the extent to which either property affects the result being dependent on the conditions of the test. Tumbler tests in general thus suffer a disadvantage, and it is difficult to compare the results of one form of test with those of another. Nevertheless, it is necessary to discuss the relative merits of the different forms of tumbler tests that are in use.

The earliest tumbler test seems to have been that used at the Clarence Iron Works by Lowthian Bell (*J. Iron and Steel Inst.*, 1904, **1**, 188), which, according to Cochrane (by whom recent interest in such tests has been reawakened), was devised by Greville Jones. Cochrane installed a similar "coke tester" at Ormesby Ironworks, Middlesborough in 1909 and reported his experience of eight years' use of it in 1918 (*J. Iron and Steel Inst.*, 1918, **1**, 141). This test, which involved the rotation of 20 to 30 lb. of coke in a drum about 30 in. in diameter during an hour at about 20 r.p.m., was further developed in America by Rice (*Amer. Inst. Min. Met. Eng.*, 1922, **67**, 596), Perrott and Kinney (*J. Ind. Eng. Chem.*, 1922, **14**, 926) and Haven (*Year-book Amer. Iron and Steel Inst.*, 1926, 171), and has been put forward tentatively as a standard test by the American Society for Testing Materials (see *Ind. Eng. Chem.*, 1928, **20**, 725).

In the meantime (1913), Simmersbach had introduced at Breslau a drum test in which 50 kg. (110 lb.) of coke were revolved 100 times at 25 r.p.m. in a drum 1 m. (39 in.) in diameter. This test was modified later by the Micum ("Mission Interalliée de Contrôle des Usines et des Mines," the international commission in control of reparations) and used to test the quality of deliveries of reparations coke. It is now widely used in Germany.

A third type of drum test, recently introduced in America, employs a drum 6 ft. in diameter in which 100 to 200 lb. of coke are revolved 50 to 100 times at 10 to 15 r.p.m. The drum is perforated to allow small coke formed by breakage to escape further disintegration.

As will be evident later, in these three types of drum tests the coke is subjected to both abrasive and impact forces, the latter becoming dominant as the diameter of the drum is increased until, as in the third type of test, they greatly preponderate. The third type of test can almost be regarded as a continuous "shatter" test.

British Tumbler Tests

Bell's Test.—A cast-iron cylinder (dimensions not specified) containing 28 lb. of coke was rotated 1000 times during 1 hr. (*i.e.* 16·6 r.p.m.). The coke was then screened over a $\frac{1}{8}$-in. sieve. From a normal beehive coke used by Bell the percentage passing an $\frac{1}{8}$-in. screen after this test was 7 and from a Hüssener oven coke it was 5·9.

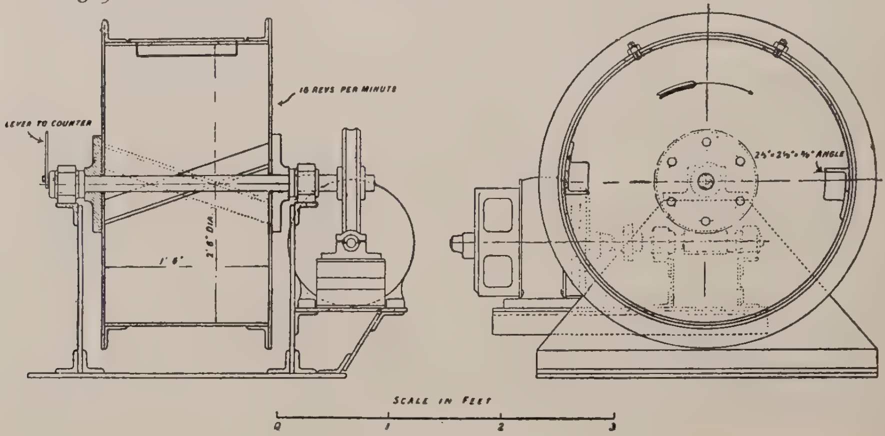


Fig. 22.—Cochrane's Tumbler Test Apparatus.

Cochrane's Test.—A drum, 30 in. in diameter and 18 in. long, fitted with two angle irons ($2\frac{1}{2} \times 2\frac{1}{2} \times \frac{3}{8}$-in.) longitudinally on its inner periphery so as to lift the coke, was used (see Fig. 22). A charge of 28 lb. of dried coke "the size of one's fist" was rotated 1000 times at 18 r.p.m. and then screened over a $\frac{1}{8}$-in. sieve. The percentage remaining on the sieve was used to express the "hardness" of the coke. Cochrane has observed that, during a period of 8 years, the driving of the blast furnace deteriorated if the "hardness" of the coke fell below 74.

The Jarrow Test.—At the Jarrow Ironworks, Durham, Hewson (*J. Soc. Chem. Ind.*, 1918, **37**, 60T) used a drum 26 in. in diameter and 16 in. long to which 28 lb. of $\frac{1}{2}$- to 1-in. coke was charged together with twelve cast-iron balls of $1\frac{1}{4}$-in diameter. The drum was rotated 1000 times during 1 hour (*i.e.* 16·6 r.p.m.) and the coke then screened over a $\frac{1}{8}$-in. sieve. The percentage remaining on the sieve was termed the "hardness number" of the coke. Hewson considered that a coke with a "hardness number" less than 94 was unsuitable for blast-furnace use. The "hardness numbers" of twenty-nine out of thirty cokes tested by Hewson lay between 93·4 and 97·5.

American Tumbler Tests

Rice's Test.—Rice, at the Bethlehem Steel Works, U.S.A., combined Cochrane's and the Jarrow test, using a drum 19 in. in diameter and 22 in. long fitted with two 1½-in. angle irons. A charge of 30 lb. of 1- to 2-in. coke, together with eleven steel balls of 1¼-in. diameter, was revolved 1240 times at 20 r.p.m. and then screened over a ½-in. sieve, the percentage of coke remaining being called the "hardness number."

Rice determined the "hardness number" and the "shatter index" (*q.v.*) of the coke charged to three 500-ton blast furnaces during 2 months and plotted these values against the "specific wind number" for the furnaces (*i.e.* the blast pressure in lb. per sq. in., divided by the blast volume in cu. ft. per min., multiplied by 1000). In general, an increase in the hardness of the coke was found to be followed by a decrease in the "specific wind number." An interesting feature of Rice's records is that the graph representing the "hardness numbers" of the coke during the test-period (averages of six consecutive periods, each of 10 days) follows that of the average 2-in. "shatter index" closely.

The U.S. Bureau of Mines Test.—Perrott and Kinney, of the U.S. Bureau of Mines, used a drum 30 in. in diameter in which a charge of 25 lb. of 2- to 3-in. coke was revolved 1200 times at 20 r.p.m. The coke was then screened over 2-in., 1½-in., 1-in., ½-in. and ¼-in. sieves. The percentage remaining on the ¼-in. sieve was called the "hardness number." In comparative tests using 3-in. and 1-in. lumps of coke, it was found that the larger coke produced the more fines, presumably because it was subjected to a greater "shatter" effect. Perrott and Kinney concluded that a coke of low shatter index, which would readily break into small pieces in the drum, might on that account show a high hardness number and that the test measured an indeterminate combination of impact and abrasion effects. Using the residues on the 1-in. and 1½-in. sieves as "hardness numbers," a series of cokes appeared in the same order as was given by the 2-in. "shatter index."

In an attempt to eliminate impact effects, Perrott and Kinney tried using charges of ¼- to ¾-in. coke and expressing the "hardness number" by the percentage remaining on a ⅙-in sieve. Amongst different cokes, however, but little difference could be observed in the resistance to attrition of the small pieces of coke rolling on each other and dropping a distance of 30 inches.

Haven's Test.—A tumbler test was used by W. A. Haven of the Republic Iron and Steel Co., Haselton, Ohio, to study the effect on the quality of coke of coal blending and variations in coke-oven practice ("Yearbook of Amer. Iron and Steel Inst.," 1926, 171). The drum was 36 in. in diameter and 18 in. long, fitted with two 2-in. angle irons, and approximated, therefore, to Cochrane's drum. A charge of 10 kg. (22 lb.) of 2- to 3-in. coke was rotated 1416 times during 1 hour (*i.e.* 23·6 r.p.m.), and then screened over several sieves between 1-in. and ⅛-in. mesh.

Haven used this test for several years. He found that a " hardness number " based on the percentage of coke remaining on a ¼-in. screen was unreliable, inasmuch as soft and friable cokes might yield only small quantities less than ¼-in. and yet break down considerably within the larger sizes. For example :

	Percentages Remaining on Different Screens.				" Hardness Number " (sum of percentages).
	1-in.	¾-in.	½-in.	¼-in.	
Republic standard coke .	37·2	14·1	6·3	4·0	61·6
Soft coke . . .	4·4	8·9	17·7	34·9	65·9

He therefore preferred to classify his cokes according to the percentage remaining on a 1-in. screen, terming this the " stability factor."

A.S.T.M. (Tentative) Standard Test.—The value attached to his test by Haven led to its recommendation by the American Society for Testing Materials (A.S.T.M.) as a tentative standard, the specification being as follows : *

" **Tumbler Machine.**—The tumbler machine shall consist of a steel drum of at least 0·25 in. plate, 36 in. inside diameter, and 18 in. inside length. Two equally spaced 2 by 2 by 0·25 in. angles are to be riveted longitudinally inside the drum. These angles are to be so riveted to the shell that the attached leg points away from the direction of rotation, thus giving a clear unobstructed shelf for lifting the coke. The drum is to be mounted on a horizontal shaft and rotated at 24 r.p.m. (tolerance ± 1 r.p.m.). An opening should be provided, preferably in the shell, for introducing and removing the sample. During the test the cover shall be rigidly fastened to the shell and shall be so constructed as to fit into the shell in order to have a smooth surface " . . .

" *Procedure.* Approximately 22 lb. (10 kg.) of the coke sample which has been previously dried, consisting of pieces which will pass a 3-in. and remain on a 2-in. square mesh sieve, shall be weighed and placed in the drum of the tumbler apparatus. The cover shall be rigidly fastened and the drum shall be rotated at 24 r.p.m. for a total of 1400 revolutions. All the coke is then removed from the drum and sieved, using the following square-mesh sieves : 2-in., 1·5-in., 1·050-in., 0·525-in., and 0·263-in. For coke larger than 2 in. each piece shall be up-ended to determine whether it passes through the 2-in. sieve in any position, while for coke smaller than 2 in. the coke shall be shaken rather vigorously in order to up-end the pieces until practically no more coke will pass through the openings. The coke remaining on each sieve and that which passes through shall be weighed separately."

---

* See " Coke Tumbler Tests," by A. R. Powell and D. W. Gould, *Ind. Eng. Chem.*, 1928, **20**, 725.

"The entire sieve analysis after the tumbler test shall be reported as cumulative per cent. to one decimal as follows:

	Per cent.	
Total retained on 2 in.	—	
Total retained on 1·5 in.	—	
Total retained on 1·050 in.*	—	(stability factor)
Total retained on 0·525 in.*	—	
Total retained on 0·263 in.*	—	(hardness factor)
Quantity passing through 0·263 in.*	—	
Total	100·0	

* For convenience these sizes will be referred to hereafter in this report as 1·0, 0·5 and 0·25 inch."

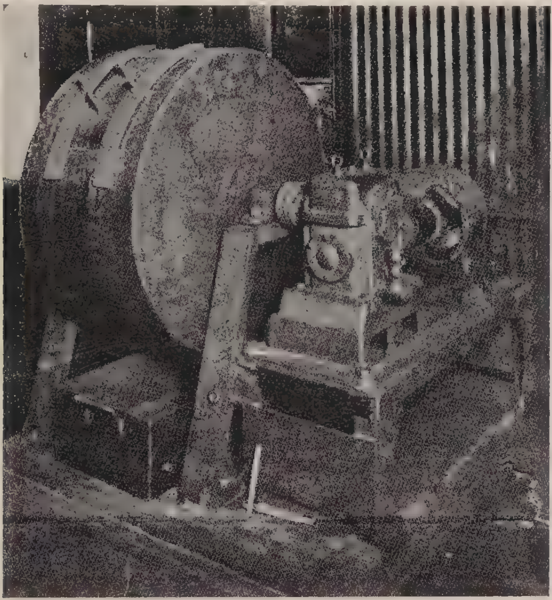


FIG. 23.—A.S.T.M. Tumbler Test Apparatus.

"Each tumbler test furnishes two significant figures which have been chosen more or less arbitrarily. The first is the 'stability factor,' which is the percentage of the original coke weight remaining on the 1-in. sieve. This is intended to serve as a measure of the ability of the coke to resist breaking up into small pieces. The other is the 'hardness factor,' which is the total percentage of the original coke's weight remaining on the 0·25-in. sieve. This is intended as a measure of the ability of the coke to resist abrasion with consequent production of breeze and dust."

Fig. 23 illustrates the A.S.T.M. Standard Test apparatus as installed at the Koppers Company's laboratories, Chicago, Ill.

Powell and Gould (*loc. cit.*, p. 727), comment on the fact that Haven, as well as Perrott and Kinney, has cast doubt on the value of the "hardness factor" and themselves conclude from tests on twenty-six cokes that it is of much less significance than the "stability factor." Admitting that the tumbler test does not imitate very closely the kind of handling to which coke is submitted at a coke-oven plant, they consider that it does reproduce, in an exaggerated degree, the degradation to which sized coke may be subjected during transmission to the point of use.

So exaggerated is the treatment of the coke in the tumbler test (there are about 3000 rolling motions over a distance of 3 ft.), that its significance as a measure of the resistance of the coke to impact must be called in question, as much as has its ability to measure resistance to abrasion. Powell and Gould, indeed, suggest that the number of revolutions of the barrel could with advantage be reduced. They obtained similar screening curves in comparative tests with the same cokes when using 1400, 1050 and 700 revolutions.

Perforated Drum Test.—M. D. Curran, of the St. Louis Coke and Iron Corporation, St. Louis, Mo., has recorded the use, for a period of 5 years, of a drum test which marked a new departure ("Yearbook of Amer. Iron and Steel Inst.," 1926, 201). Curran, who defined the "strength" of a coke as its resistance to both impact and abrasion and its "brittleness" as its lack of resistance to impact, considered that in a drum test the smaller coke pieces, produced by breakage of the larger, should be removed before they suffered disintegration. He therefore used a drum of perforated plate (1½-in. apertures), 6 ft. in diameter, fitted with a series of lifting flights. A charge of 200 lb. of coke (a quartered sample from the coke wharf) was revolved 100 times during 10 minutes (10 r.p.m.) and then screened in a small trommel screen with ½-, 1-, 1½- and 2-in. sieves. The following weights were also determined: the weight of the sample (T), *i.e.* 200 lb.; the weight of coke remaining in the drum (R); and the weight of coke that had passed through the perforations (D).

From these determinations, the following relationships were deduced:—

$$\text{Strength of coke} = \frac{\text{On 2-in.}}{R} \times \left\{\frac{\text{On 2-in.} \times \text{On } 1\tfrac{1}{2}\text{-in.}}{\text{On } 1\tfrac{1}{2}\text{-in.} \times \text{On 1-in.}}\right\} + \frac{R}{T} + \left\{\frac{\text{On } 1\tfrac{1}{2}\text{-in.} \times \text{On 1-in.}}{D \times T}\right\}^2$$

$$\text{Hardness of coke} = D - \frac{\text{Through 2-in.}}{T} - \frac{\text{Through 1-in.} \times \text{D}}{T^2}.$$

$$\text{Brittleness of coke} = \frac{D - \text{Through } \tfrac{1}{2}\text{-in.}}{T}$$

$$\text{Fuel Value} = \frac{\text{Strength}}{\text{Hardness}} \times \frac{\text{Brittleness}}{\text{Weight}}.$$

F. F. Marquard ("Yearbook of Amer. Iron and Steel Inst.," 1928, 95) records that a test and empirical formulæ of this type were adopted by the By-Product Coke Corporation at South Chicago and by the Toledo Furnace Company. Similarly, at the Clairton works of the Carnegie Steel Company, a drum 6 ft. in diameter and 2 ft. 8 in. long was used. The drum was perforated by $1\frac{1}{2}$-in. round holes, staggered at 2-in. centres, and was fitted inside with five 6-in. longitudinal angle-irons. A charge of 100 lb. of $2\frac{1}{2}$- to 4-in. coke (square mesh) was rotated fifty times during 4 minutes (13 r.p.m) and that remaining in the drum riddled on a 2-in. mesh. The coke that had passed through the perforations was screened on 1-in. and $\frac{1}{2}$-in. sieves. The following weights were noted: Weight of coke in drum, on 2-in. (A); weight of coke in drum, through 2-in. (B); weight of coke through drum perforations, on 1-in. (C); weight of coke through perforations, on $\frac{1}{2}$-in. (D); weight of coke through perforations, through $\frac{1}{2}$-in. (E); weight of dust lost (F); total weight of coke in drum, *i.e.* $A + B$, (G); coke less than 1-in. that had passed through drum perforations, *i.e.* $D + E + F$, (H); total weight of coke that had passed through drum perforations, *i.e.* $100 - G$, (K). From these determinations the following relationships were deduced:

$$\text{Mean strength of coke} = \frac{100 \times A \times B}{C \times G} + G + \frac{C^2}{K}.$$

$$\text{Hardness} = 100 - H.$$

$$\text{Brittleness} = C + D.$$

$$\text{Fuel Value} = \frac{\text{Strength} + \text{Hardness} - \text{Brittleness} \times (100 - \text{Ash})}{100}$$

Expressed in words, this formula, which was adapted to produce a fuel value factor in accord with Clairton experience, makes the "hardness" index the percentage of coke remaining on a 1-in. sieve at the end of the test, whilst in Curran's formula it is a function of the amount of coke remaining on a 2-in. sieve. "Brittleness" in both formulæ is expressed by the amount of $\frac{1}{2}$- to $1\frac{1}{2}$-in. coke produced. The formulæ for "strength" are more difficult to state in words. They are related to a function of on 2-in., on $1\frac{1}{2}$-in. and on 1-in. sizes of coke remaining at the end of the test, the larger sizes being credited more highly than the smaller.

German Tumbler Tests

Simmersbach's Test.—At Breslau, Simmersbach used a testing machine to measure the crushing strengths of cubes of coke and devised a tumbler or "trommel" test intended to measure abradability (*Stahl u. Eisen*, 1913, **33**, 512). The drum was 1 m. (39 in.) in diameter and 0·5 m. (about 20 in.) long. A charge of 50 kg. (110 lb.) of coke was revolved in it 100 times during 4 min. (25 r.p.m.) and then screened over round-hole sieves of 100, 80, 40, 25 and 10 mm. aperture. The percentage of the coke remaining on the 40-mm. sieve was taken as its index of resistance to abrasion. The following examples were given by Simmersbach:

Description of Coke.	Index.
Unusually hard coke	90
Very hard coke	85
Hard coke	80
Fairly hard coke	75
Soft coke	<75

This test, sometimes termed the Breslau test, was modified to provide the " Micum " test.

The " Micum " Test. The Mission Interalliée de Contrôle des Usines et des Mines in 1924 adopted the principle of the Breslau test to assess the quality of reparation coke delivered by Germany to other European countries. The length of Simmersbach's drum was doubled, and four angle-irons were fitted longitudinally at the periphery to lift the coke as the drum revolved. The official description of the apparatus (*Stahl u. Eisen*, 1927, **47**, 1867; see also *The Fuel Economist*, 1927, **3**, 183) is as follows:

" **Determination of the Physical Resistance of Coke.** The coke is to be tested in a cylindrical drum of steel plate one metre in length and one metre in diameter. The drum is to be provided with four angle-irons, with legs of 100 mm., fixed 90° apart on its walls; and a door 500 by 600 mm. in its side for the introduction of the coke sample.

" Four tests are to be carried out, each with 50 kg. of the coke, the drum being rotated 100 times in 4 minutes, a margin of 10 seconds above or below 4 minutes being allowed, if necessary, to complete the 100 revolutions. The mean of the four tests is to be taken as the result.

" As far as possible, the coke taken for the tests should be from the consignee's wagons or as it comes from the loading place. It may be taken from a laden train, or, exceptionally, from the coke which falls when the door of a laden wagon is dropped. The samples must be taken with a fork the prongs of which are 50 mm. apart, each 50 kg. sample being placed in a metal container. The larger coke pieces are to be placed by hand in the testing drum; only the smaller and lighter pieces are to be emptied directly into the drum from the container. After the drum has been revolved 100 times, the coke is passed twice over a plate screen with circular 40-mm. holes. To conform with the required standard of strength, at least 72 per cent. of the coke sample must remain on such a screen after the test."

A diagram of the " Micum " trommel test apparatus is reproduced in Fig. 24.

G. Dorflinger (*Stahl. u. Eisen*, 1927, **47**, 1867) has found that with Upper Silesian and Sarre cokes the " Micum " index is only from 25 to 55 and suggests that the tested coke should be screened over a 10-mm. as well as a 40-mm. screen to indicate the quantity of fines produced; for two cokes might yield the same amounts of over 40-mm. sizes but very different amounts of fines, and should not be assessed as of the same value. In support of this contention, Dorflinger records the results of daily tests over a period of 30 days.

We have made comparative tests on a number of cokes with the "Micum" trommel apparatus and the "shatter" apparatus (*q.v.*) and find that, broadly speaking, they are placed in the same order of hardness by both tests.

The Northern Coke Research Committee have studied the effect of modifying details of procedure with the "Micum" trommel test (*Fuel* 1929, **8**, 411). They found that the use of a 50 lb. charge of coke, instead of 50 kg. (110 lb.), in the "Micum" drum caused more severe breakage, but that if the length of the drum were halved a 50-lb. charge gave nearly the same result as a 50-kg. charge in the "Micum" drum. In other words, the extent to which the coke fills the drum has an important effect on the result of the test.

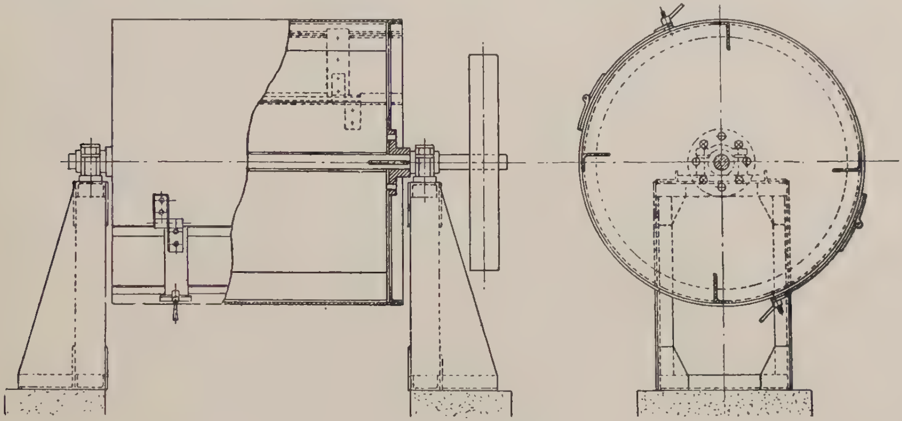


FIG. 24.—"Micum" Trommel Test Apparatus.

The Northern Coke Research Committee's comparison of the results of "Micum" and "shatter" tests on a number of cokes placed the cokes in roughly the same order of hardness as did ours, whilst they found also that, with few exceptions, the tendency for the cokes to produce fines was indicated in a like degree by the two tests, the ratio of the amount of through 10-mm. breeze in the "Micum" test to the amount of through $\frac{1}{2}$-in. breeze in the "shatter" test being reasonably constant. Since in the "shatter" test the breeze is produced entirely by impact, the Committee concluded that the "Micum" test is virtually no more than a modified "shatter" test, in which the force of impact alone plays a significant part, and from which no indication of the relative abradability of cokes is obtained.

FRENCH TUMBLER TEST

Carton's Test.—A method of test devised by V. L. Carton has been used in France and Belgium (see Illingworth, "The Analysis of Coal and its By-Products." London, 1921). A drum 550 mm. (21¾ in.) in diameter and 150 mm. (6 in.) long is rotated 600 times during 15 min. (40 r.p.m.) with a charge of 6 kg. (13·2 lb.) of coke and a number of steel balls. After the test, the coke is screened over a 19-mm. (¾-in.) sieve.

From these brief descriptions of a selection of the various tumbler tests that have been proposed, it will be realised that they can serve a useful purpose, perhaps more particularly as an adjunct to the study of the effects of different conditions of coking on the quality of the coke produced. Several observers have noted, however, that the " hardness " of a coke cannot properly be assessed by an " index " dependent on the proportion of very fine coke, less than ½-in., for example, produced during the test. In general, experience points to a test of the kind suggested by the American Society for Testing Materials, and the " stability factor " (1-in. screen) it provides, as the most informative. The fact must be emphasised, however, that the " stability factor " obtained by such a test corresponds closely with the " shatter index " (2-in. screen). In other words, a tumbler test of that character gives a measure of the liability of the coke to breakage by impact (or its " true hardness " as we have defined it). It is not, therefore, a test of abradability, such as is its intention, though abrasion forces must be operative, for the coke pieces after the test are usually rounded.

THE DEVELOPMENT OF A TEST OF ABRADABILITY OF COKE

We have made a study of tumbler tests with a view to modify them so as to obtain a satisfactory measure of the abradability of coke, bearing in mind that for that purpose the test should avoid the introduction of impact forces.

Screening after Tumbler Test. In our earliest experiments we treated 25 lb. of over 2-in. coke in a drum 18 in. in diameter and 9 in. long (Fig. 25), revolved during 1 hour at 23 r.p.m. The percentage amounts of coke remaining on different screens were then determined, as recorded in Table XXII.

The notable result of these tests is the production of quantities of through $\frac{1}{16}$-in. dust, showing that some abrasion was occurring. In order to determine the extent to which abrasive, rather than impact, forces might be presumed to be operative, series of tests were now made using different weights of coke in the same drum, so that the amount of free space in which the coke could fall was varied.

The Effect on Abrasion of Varying the Free Space in the Drum.—The drum when completely filled could hold about 30 lb. of a moderately dense coke of over 2-in. size. Taking four good quality cokes, different weights were revolved during 1 hour at 23 r.p.m. The resulting sieving analyses, expressed as cumulative percentages, are recorded in Table XXIII.

TABLE XXII.—SCREENING AFTER TUMBLER TEST

Coke No Origin. Reputation.	1. S. Wales. Excellent.	2. Durham. Very good.	3. Yorkshire. Good.	4. Yorkshire. Fair.
Per cent.				
On 2-in.	91·4	76·2	83·3	70·6
2-in. to $1\frac{1}{2}$-in.	Nil	8·4	4·9	13·3
$1\frac{1}{2}$-in. to 1-in.	Nil	4·3	4·4	4·0
1-in. to $\frac{1}{2}$-in.	0·1	2·0	2·0	4·0
$\frac{1}{2}$-in. to $\frac{3}{8}$-in.	0·1	0·2	0·1	0·3
$\frac{3}{8}$-in. to $\frac{1}{4}$-in.	0·1	0·5	0·2	0·5
$\frac{1}{4}$-in. to $\frac{1}{8}$-in.	0·1	0·5	0·2	0·5
$\frac{1}{8}$-in. to $\frac{1}{16}$-in.	0·2	0·2	0·1	0·1
Through $\frac{1}{16}$-in.	8·0	7·7	4·8	6·7
" Shatter Index " (2-in./$1\frac{1}{2}$-in.)	94/97	79/90	77/86	68/80

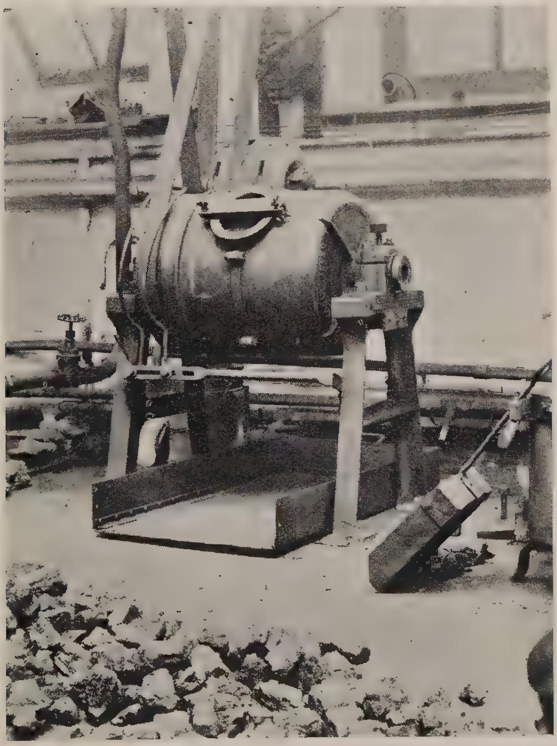


FIG. 25.—Sheffield Drum Abrasion Test Apparatus.

TABLE XXIII.—THE EFFECT ON ABRASION OF VARYING THE FREE SPACE IN THE DRUM

	Cumulative Percentages Remaining on Sieves.					Percentage through $\frac{1}{16}$-in.
	2-in.	1½-in.	1-in.	½-in.	$\frac{1}{16}$-in.	
Coke No. 1 (S. Wales)						
5 lb.	61·1	88·4	89·4	90·4	91·4	8·6
10	50·6	85·6	89·4	90·0	90·6	9·4
15	49·4	85·1	87·5	88·2	88·9	11·1
20	80·7	89·9	90·2	90·5	91·1	8·9
25	86·4	95·7	95·9	96·2	96·7	3·3
29*	89·0	98·1	98·3	98·5	98·7	1·3
Coke No. 5 (Durham)						
5 lb.	—	72·1	83·6	91·2	93·8	6·2
10	—	77·5	89·4	91·9	93·1	6·9
15	—	62·9	94·2	95·0	95·4	4·6
20	—	77·1	91·1	93·9	94·9	5·1
25	—	76·2	90·7	92·7	93·7	6·3
30	—	79·9	95·1	96·1	96·3	3·7
42·2*	—	95·8	99·1	99·2	99·3	0·7
Coke No. 6 (Durham)						
5 lb.	57·8	76·8	81·0	82·1	83·2	16·8
10	51·7	82·1	86·7	87·9	89·1	10·9
15	54·9	81·6	85·4	88·0	89·7	10·3
20	37·3	79·8	84·9	87·4	89·3	10·7
25	67·5	89·5	92·3	93·3	94·5	5·5
30	65·0	96·3	97·0	97·2	97·4	2·6
32·7*	84·2	97·3	97·5	97·7	97·9	2·1
Coke No. 10 (Westphalia)						
5 lb.	40·0	82·5	85·0	87·5	88·7	11·3
10	65·0	85·6	90·0	90·6	91·2	8·8
15	68·3	88·0	88·4	89·2	89·6	10·4
20	40·5	84·4	89·9	90·8	91·4	8·6
25	55·5	89·5	93·0	93·5	94·0	6·0
30	78·2	96·1	96·1	96·3	96·5	3·5
32*	83·6	96·4	96·4	96·6	96·8	3·2

* Drum completely filled.

These tests show clearly that, as the amount of drum-space occupied by coke increased, breakage of the coke by impact decreased. The sieving analysis figures for on 1½-in. coke give the best indication of the extent to which breakage by impact has occurred, for the amount of on 2-in. coke is reduced partly by abrasion of the pieces. The amount of abrasion, as indicated by the through $\frac{1}{16}$-in. dust produced, also decreased as the drum became filled with coke. The quantities of dust formed when only small charges of coke were used were, however, in part due (as later experiments showed) to the increased surface afforded during the test by breakage of the coke by impact. With quantities of 25 or 30 lb. of coke (the drum space being then 80 to 95 per cent. occupied), the effect of breakage by impact was obviously small and it appeared that the amounts of through $\frac{1}{16}$-in. dust could be taken as giving a fair measure of the effect of abrasion.

It was therefore decided, as a preliminary step in the evolution of a test of the abradability of coke from some form of " tumbler " test, to employ charges of coke of not less than 25 lb., representing, for the particular drum we had installed, about 80 per cent. filling. This percentage filling may usefully be compared with that obtaining in the various tumbler tests previously described, thus :

Name of Tumbler Test.	Drum Space Occupied by Coke (per cent. of total).
Cochrane	15
Jarrow	23
Rice	38
Haven	9
Micum	21

Our 80 per cent. filling was thus a notable departure from previous practice.

The Effect on Abrasion of the Size of the Coke Pieces Tested.—In any measurement of the abradability, or surface hardness, of coke from the quantity of dust produced during a " tumbler " test, the amount of surface exposed to the abrasive forces would be expected to influence the results. Comparative tests to give information on this point were made with 25-lb. charges of coke of different sizes revolved during 1 hour at 23 r.p.m. The results are recorded in Table XXIV.

TABLE XXIV.—THE EFFECT ON ABRASION OF SIZE OF COKE PIECES TESTED

Coke.	Size (in.)	Percentage of through $\frac{1}{16}$-in. Dust Formed.
Beehive (S. Yorks.)	On 2	3·0
	2 to $1\frac{1}{2}$	4·0
	$1\frac{1}{2}$ to 1	6·0
No. 5 (Durham) . . .	On 2	8·0
	2 to $1\frac{1}{2}$	8·2
No. 6 (Durham) . . .	On 2	5·0
	2 to $1\frac{1}{2}$	6·0
No. 4 (Yorks.)	On 2	6·7
	2 to $1\frac{1}{2}$ (undried)	8·5
	2 to $1\frac{1}{2}$ (dried)	8·1

These tests show clearly the necessity, when attempting to standardise an abrasion test, for using coke of graded size to ensure as far as possible constancy of the amount of surface exposed to the abrasion forces. It was accordingly decided to use 3- to 2-in. coke pieces in all future tests.

Attention may here be called to the parallel tests with dried and undried coke recorded in Table XXIV, for they enabled us to decide on a further detail of the proposed abrasion test. The undried coke, one of the wettest that has been delivered at the laboratories, contained 9·4 per cent. of moisture. The proportion of through $\frac{1}{16}$-in. dust formed from this coke when wet was but little different from that formed after it had been dried. Since most of the coke samples received at the laboratories have full opportunity for becoming air-dried before they are tested, it was concluded that no special pains need be taken to bring each coke sample tested to a uniform state of dryness.

The Effect of the Duration of the Test.—The coke pieces (25 lb. of 3- to 2-in. size) after treatment during 1 hour in our drum had a more markedly rounded appearance than that of coke pieces extracted from the tuyeres of a blast furnace. An attempt was therefore made to reproduce more closely the blast-furnace appearance by varying the severity of the test, *i.e.* by varying its duration.

Several samples of cokes were treated during $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$ and 1 hour and the appearance of the pieces was then compared with that of pieces of the same origin that had passed down the shaft of a blast furnace and been extracted at the tuyeres. Typical examples are illustrated on Plates XXIV and XXV. In general, it seemed that a treatment for $\frac{1}{2}$ hour in the drum yielded coke pieces most closely resembling those from the blast furnace. Treatment for $\frac{1}{2}$ hour was therefore adopted as standard.

It now became necessary to attempt a closer standardisation of the "drum abrasion test" so far developed, by comparing the results given by it with those given by a "true abrasion test," in which surface abrasion of the coke was known to be the only force operating.

Comparison of Drum Abrasion with True Abrasion Test.—A. Schmolke (*Gluckauf*, 1923, **59**, 3) had devised a true abrasion test for coke which seemed suitable for our purpose. A ground surface of the coke is held against a rotating emery wheel at known pressures and the amount of powder removed during a given time determined. The apparatus is illustrated in Fig. 26. A cube of coke is clamped securely to a vertical bar suspended from a knife-edge. At right angles to the vertical bar, near to the point of suspension, is a threaded rod carrying a lead balance-weight the movement of which along the rod allows of varying the pressure of the coke surface against the rotating emery wheel.

When carrying out a test, several of the faces of a 2-in. cube of coke, cut from the coke sample with a hack-saw or a carborundum

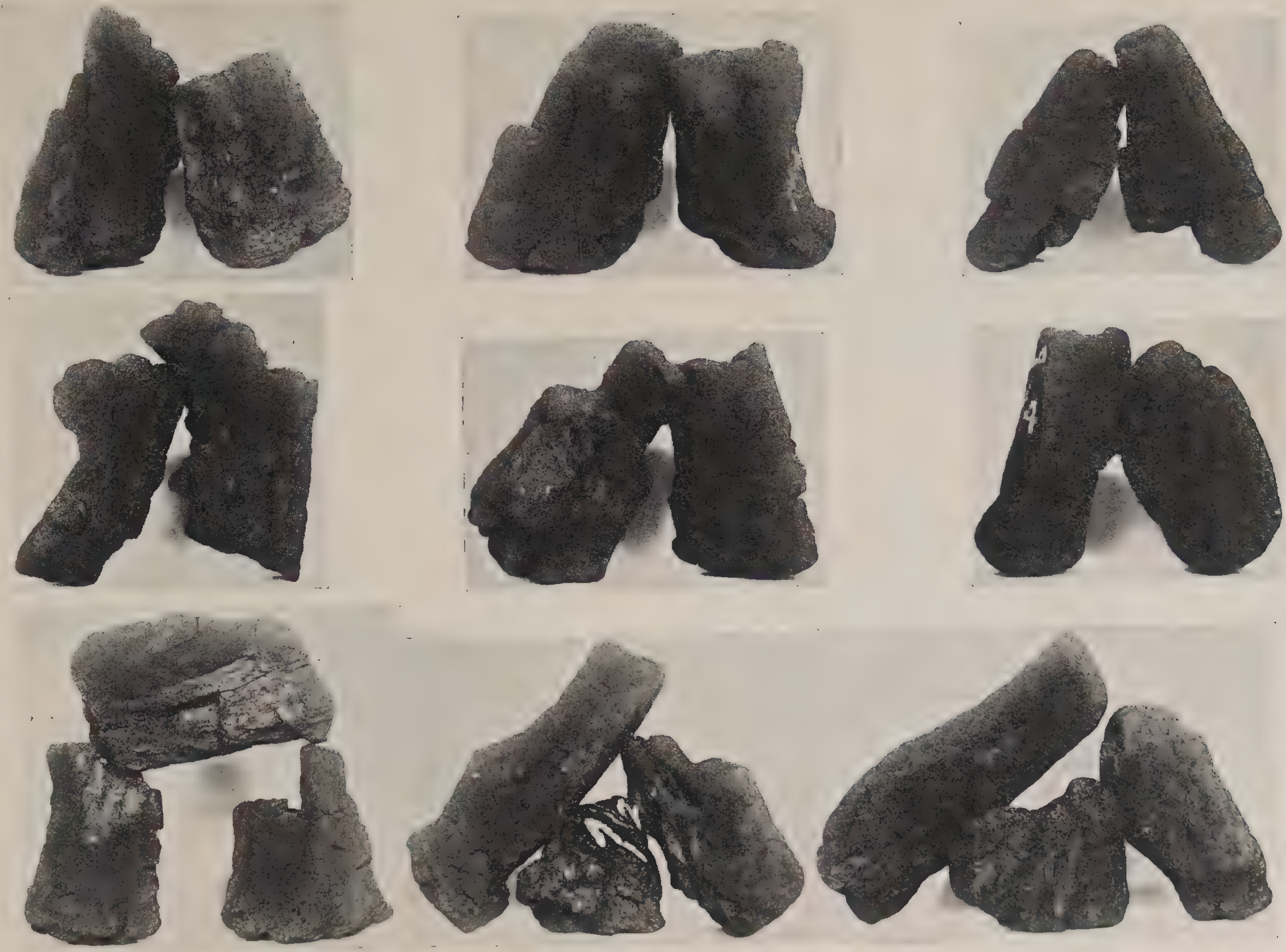

Time of treatment.
$\frac{1}{4}$ hr.
$\frac{1}{2}$ hr.
$\frac{3}{4}$ hr.
Coke
No. 20B.
2A.
7

PLATE XXIV.—Appearance of Coke after Treatment in Drum Abrasion Apparatus for Various Periods.

[*To face p.* 86.

K

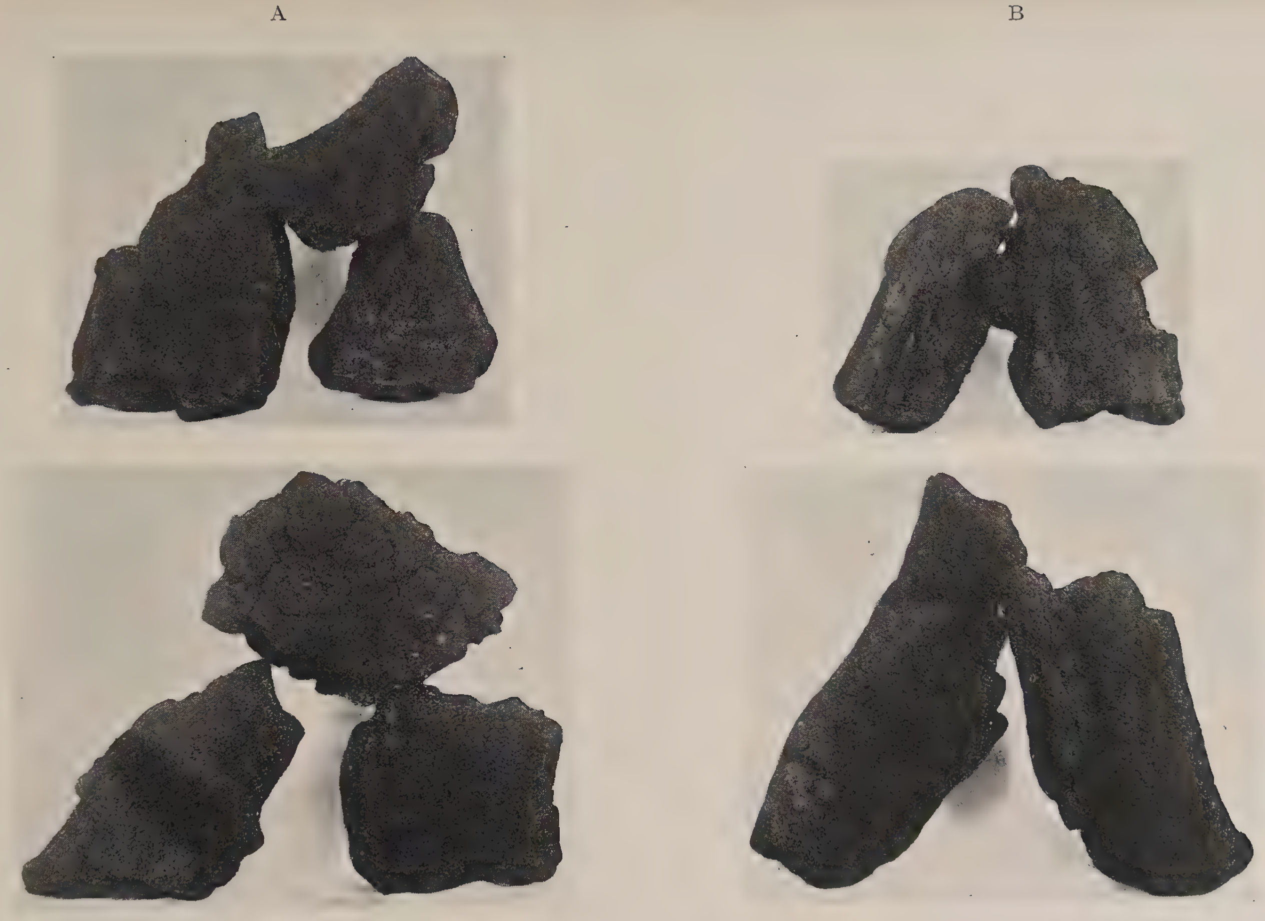


PLATE XXV.—Comparison of Coke Raked from Tuyeres (A), with Coke Treated for ½ hr. in Drum Abrasion Test (B).
(See also Plate V.)

[*To face p.* 86.

cutting wheel, were subjected to 15-sec. periods of grinding against the emery wheel rotating at 1750 r.p.m., and the loss in weight from each face was determined separately. The mean loss in weight can be expressed in grams per 100 sq. cm. of coke surface. Details with regard to the effect of alterations in the experimental conditions on the results given by this test are given in an appendix to this chapter.

The order of abradibility of a series of seven cokes as determined by this test is compared in Table XXV with their order as given by drum abrasion tests.

Table XXV.—Comparison of Order of Abradability of Cokes as given by True Abrasion and Drum Abrasion Tests

	Order of Abradability. Coke Numbers.						
True abrasion test . . .	1	2	4	7	6	3	5
Drum abrasion test: (*a*) Using 25 lb. of coke;* duration 1 hr.	5	1	2	4	6	7	3
Drum abrasion test: (*b*) Using drum completely filled with coke; duration 1 hr. . .	1	2	3	6	7	4	5

* Drum about 80 per cent. filled with coke of average density.

The cokes, which included three Durham, three Yorkshire and one Welsh, fell in about the same order of abradability by the true abrasion test and the drum abrasion test (*a*). Coke No. 5 was a notable exception, for it was the least abraded in the former and the most abraded in the latter test. This coke was unusually dense and brittle and the position assigned to it by the drum abrasion test was no doubt due to early breakage of the larger pieces by impact. With this unusually dense coke, 25 lb. occupied but 60 per cent. of the volume of the drum. Bearing in mind the likelihood of anomalous results on occasion, it was considered that the general agreement between the true abrasion test and the drum abrasion test using 25 lb. of coke showed that the effect of impact forces in the latter was not serious, and that it could usefully be employed for routine testing of the abradability of a number of cokes with a view to ascertain its limitations.

The drum test so far developed, *i.e.* the revolution of 25 lb. of 3- to 2-in. coke in a drum 18 in. in diameter and 9 in. long during $\frac{1}{2}$ hour at 23 r.p.m., was therefore applied to 112 cokes. It early became evident that the conditions of test were not entirely satisfactory for abnormally dense cokes, for 25 lb. of such cokes did not occupy a sufficient volume of the drum. When the results for about sixty cokes were available, it was noted that with about half of them the proportion of on $1\frac{1}{2}$-in. coke remaining at the end of the test was 95 per cent. or more. For these cokes, the percentage of through $\frac{1}{16}$-in. dust was low. Of the remaining cokes, the screening analysis of half showed between 95 and 90 per cent. of on $1\frac{1}{2}$-in. pieces and that of the other half between 90 and 80 per cent. or less (as little as 63 per cent. in one instance). A low "on $1\frac{1}{2}$-in." percentage was generally associated with a high "through $\frac{1}{16}$-in." percentage. It was therefore considered that the on $1\frac{1}{2}$-in. percentage might appropriately be used as the "abrasion index," for, assuming that the test reproduced approximately the attrition to which coke is subjected during its passage down the shaft of a blast-furnace, the on $1\frac{1}{2}$-in. percentage more properly expresses the amount of useful coke remaining than does the through $\frac{1}{16}$-in. percentage. Moreover, this $1\frac{1}{2}$-in. "abrasion index" would conform with the use of a similar figure for the "shatter index" (*q.v.*), should that be found to be desirable, and a combination of the two indices could conveniently be used to express the general mechanical strength of a coke, its resistance to both impact and abrasion.

Certain anomalies were observable. Of seventeen cokes having an "abrasion index" of less than 90, ten were made from compressed charges (including seven from Derbyshire), four were anthracite blends and three were made solely from "hards" (durains). From this it appeared that the test was still on occasion measuring something other than abradability. For "compressed" cokes are not usually regarded as being readily abraded and they did not, in fact, produce much through $\frac{1}{16}$-in. dust during the test. On the other hand, the cokes made from anthracite blends and from hards produced much dust. The test was proceeded with unaltered, however, paying particular attention to the effect of the different densities of the cokes tested.

The Effect of the Bulk Density of the Coke.—Owing to the different densities of the cokes tested, the 25 lb. charge of 3- to 2-in. size occupied from 0·71 to 1·25 cu. ft. The test results obtained can be analysed as follows :

High Volumes (charge occupying more than 1·1 cu. ft.).—In tests on thirty-six cokes, no "abrasion index" fell below 90 except with certain very friable cokes made from blends with low-temperature coke breeze, cokes so friable that they could be rubbed to pieces with the fingers.

Low Volumes (charge occupying less than 1 cu. ft.).—In tests on thirty-four cokes, the following "abrasion indices" were obtained :—

Volume.	Result.
1·0 to 0·95 cu. ft.	One coke out of seven (14 per cent.) had an index less than 90. This coke had been made from hards and a low index was to be anticipated.
0·95 to 0·90 cu. ft.	Five cokes out of twelve (42 per cent.) had indices less than 90, three being less than 85.
0·90 to 0·85 cu. ft.	Four cokes out of eight (50 per cent.) had indices less than 90, one being less than 85.
Less than 0·85 cu. ft.	Six cokes out of seven (86 per cent.) had indices less than 85.

This analysis made it clear that, although it might be more difficult to standardise, the test should be made using a constant volume of coke rather than a constant weight. Tests of a number of cokes were therefore repeated using 1 cu. ft. of 3- to 2-in. pieces.

The Effect of Using a Constant Volume of Coke.—The results of tests in which a constant volume of 1 cu. ft. of coke was used were as follow :

High Volume Cokes.—Twenty-four of the thirty-six cokes 25-lb. charges of which had a volume greater than 1·1 cu. ft. were re-tested, using 1 cu. ft. No marked differences in the results were observed.

Low Volume Cokes.—Seventeen of the thirty-four cokes 25-lb. charges of which had a volume less than 1 cu. ft. were re-tested, using 1 cu. ft. The results are recorded, and compared with those obtained when 25-lb. charges were used, in Table XXVI.

TABLE XXVI.—ABRASION INDICES OF COKES USING (*a*) 25-LB. AND (*b*) 1 CU. FT. CHARGES

Coke No.	Tests using 25-lb. Charges.			Tests using 1 cu. ft. Charges.	
	Vol. of 25 lb. (cu. ft.).	Abrasion Index.	Through $\frac{1}{16}$-in. (per cent.).	Abrasion Index.	Through $\frac{1}{16}$-in. (per cent.).
13C(*b*)	0·88	87·9	9·2	94·3	3·5
13D(*b*)	0·79	74·8	9·8	94·8	2·6
*17B	0·92	76·7	3·3	98·0	0·4
*17J	0·92	93·5	2·0	98·8	0·4
*17L	0·92	91·7	2·8	99·0	0·6
*25A	0·81	78·8	9·3	98·8	1·0
*25B	0·83	83·0	10·0	98·8	1·0
*29H	0·83	84·5	3·5	98·6	0·6
*32	0·92	84·4	2·7	99·0	0·4
*33	0·88	91·0	2·0	98·6	0·6
34	0·92	91·0	2·5	97·0	1·1
*35	0·88	87·8	2·6	99·0	0·6
*36A	0·92	91·9	1·8	99·0	0·4
*36B	0·92	96·3	2·7	98·4	0·6
*37	0·88	75·7	2·7	97·4	0·6
3F (I)	0·92	97·3	1·5	98·9	0·7
3F (II)	0·88	97·1	1·2	98·7	0·7

* Made from compressed charges.

A low volume of a 25-lb. charge is in twelve instances out of the seventeen given by a coke made from a compressed charge, and all these gave high abrasion indices when 1 cu. ft. charges were used. For only two of the 1 cu. ft. charges were abrasion indices of less than 95 obtained, namely for cokes Nos. 13C (*b*) and 13D (*b*), which had been made respectively from fine dust and from slurry.

What may be termed "The Sheffield Coke Abrasion Test" is finally specified as follows: In a drum 18 in. in diameter and 9 in. long, 1 cu. ft. of 3- to 2-in. coke is revolved during ½ hour at 23 r.p.m. Alternatively, there is no objection to using a drum 18 in. in diameter and 18 in. long, with a charge of 2 cu. ft. of coke. A sieving analysis is then made and the percentages of the charge remaining on a 1½-in. screen and passing through a $\frac{1}{16}$-in. screen are noted. The percentage remaining on a 1½-in. screen is taken to be the "abrasion index."

Most of the cokes received at the laboratories have been submitted to this test. It is of interest to examine the character of cokes that have shown low abrasion indices. These are listed in Table XXVII.

TABLE XXVII.—COKES OF LOW ABRASION INDEX (SHEFFIELD TEST)

Coke No.	Abrasion Index.	Through $\frac{1}{16}$-in. (percent.)	Coal Used.
22E	89·8	3·0	Deep Soft seam, Derbyshire.
22C	89·3	1·5	Deep Soft seam with 30 per cent. Barnsley seam, Yorks.
17D	88·1	4·0	Barnsley hards, Yorks.
22A	87·8	2·0	Deep Soft seam with 30 per cent. Barnsley seam.
28E	84·5	2·3	Waterloo seam, Derbyshire.
17C	83·3	4·1	Parkgate hards, Yorks.
9	83·2	6·0	Yorkshire coking slack with 20 per cent. anthracite duff.
38C (iv)	80·4	4·0	Yorkshire coking slack with 22 per cent. low-temperature coke breeze.
13B (*b*)	80·2	6·3	Yorkshire coking slack with 10 per cent. Parkgate hards.
22B	80·2	2·1	Deep Soft seam with 30 per cent. Barnsley seam.
38C (i)	78·9	2·3	Yorkshire coking slack with 9 per cent. low-temperature coke breeze.
38C (iii)	75·5	4·8	Yorkshire coking slack with 18 per cent. low-temperature coke breeze.
22G	71·6	5·3	Derbyshire coking slack with 18 per cent. low-temperature coke breeze.
28C	62·8	8·6	Deep Hard seam, Derbyshire.
38C (ii)	43·4	9·5	Yorkshire coking slack with 12 per cent. low-temperature coke breeze.

All the cokes in this list were made either from single seams of coal of low caking and swelling power or from blends containing non-caking material. Low abrasion indices for such cokes are readily understandable. The only commercial coke on the list is the first, No. 22E, the others being experimental cokes many of which would no doubt be condemned as unsaleable on visual examination. As a tentative standard, it might be suggested that no coke giving an abrasion index of less than 90 under the conditions of test specified is likely to find a ready sale. Most commercial cokes have a considerably higher abrasion index than 90, and it would seem that the majority cannot experience much loss by attrition in the shaft of a blast furnace. A test of the abradability of coke is not, therefore, normally of much practical importance, but, if reliable, it undoubtedly serves a useful purpose in a study of the products obtained during experimental work on coke manufacture.

APPENDIX

A True Abrasion Test

When carrying out a true abrasion test of the character devised by Schmolke (*loc. cit.*), a number of points of detail have to be observed, lest the results should be misleading and the deductions drawn from them erroneous. We have carried out a number of series of tests with the apparatus illustrated in Fig. 26, to obtain standardised procedure, and here place some of the results on record for the information of others who may desire to employ such a test.

The Results of Successive Tests.—Cubes were cut from a number of cokes and submitted to successive abrasion tests in the manner described in this Chapter. The results are given in Table I, the loss on abrasion being expressed in grams per 100 sq. cm. of surface.

Table I.—Successive True Abrasion Tests of Cokes

Coke No.	Abrasion Loss (grams per 100 sq. cm.)		Order of Abradability.	
	Test I.	Test II.	According to Test I.	According to Test II.
1 (S. Wales) .	17·8	8·3	1	1
2 (Durham) . .	7·9	7·8	3	2
3 (Yorkshire) .	3·9	2·8	7	7
4 (Yorkshire) .	5·0	6·8	6	3
5 (Durham) . .	6·4	3·6	5	6
6 (Durham) . .	7·0	3·9	4	5
7 (Yorkshire) .	8·8	4·8	2	4

During the first series of tests it was evident that the more pronounced irregularities of the coke surfaces were rubbed away, giving perhaps a false estimate of their abradability. The necessity for successive tests, from which a mean result might be taken, was therefore apparent.

Comparison of Abradability of Longitudinal and Transverse Surfaces.—Three successive tests were made on (i) a longitudinal and (ii) a transverse face of fresh cubes from the cokes listed in Table I, two cubes, *a* and *b*, being taken from each. The results are recorded in Table II.

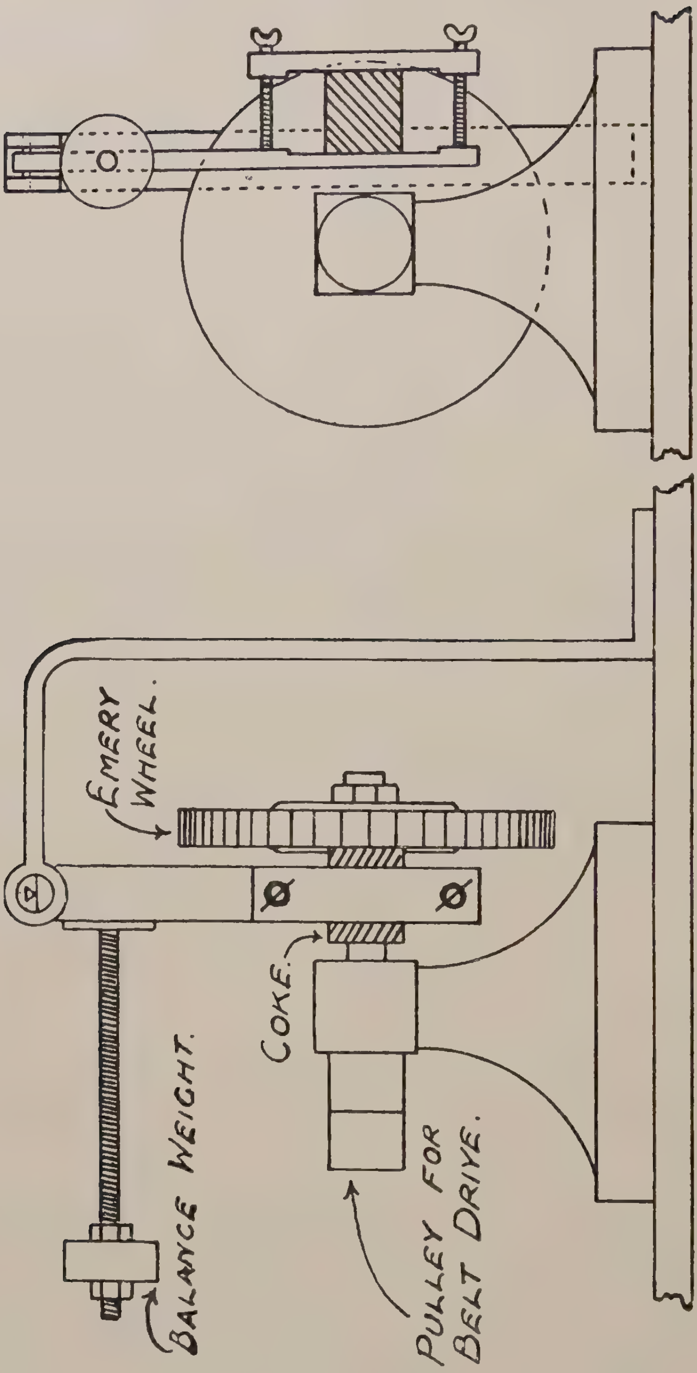

EMERY WHEEL.
COKE.
BALANCE WEIGHT.
PULLEY FOR BELT DRIVE.

FIG. 26.—Diagram of True Abrasion Test Apparatus.

Table II.—Tests of Abradability of Longitudinal and Transverse Coke Surfaces.

Coke No.	Longitudinal Faces.			Transverse Faces.		
	Test I.	Test II.	Test III.	Test I.	Test II.	Test III.
1 (*a*)	11·7	4·3	3·6	2·0	1·9	1·3
(*b*)	12·2	5·3	4·0	2·4	5·0	3·7
2 (*a*)	8·3	3·8	3·2	4·7	3·2	1·6
(*b*)	4·7	2·0	0·7	0·9	1·4	0·8
3 (*a*)	9·2	4·2	4·0	2·4	2·2	1·2
(*b*)	6·1	3·0	1·9	8·8	6·1	4·5
4 (*a*)	5·4	2·5	2·6	3·0	2·1	1·6
(*b*)	4·8	2·2	2·1	3·6	1·6	1·7
5 (*a*)	2·7	1·2	2·4	1·8	1·9	1·3
(*b*)	1·3	0·6	0·7	1·9	1·6	1·7
6 (*a*)	2·2	2·8	2·3	1·9	2·2	1·1
(*b*)	1·8	1·4	1·4	1·1	0·5	0·9
7 (*a*)	2·5	1·8	1·9	1·8	1·6	1·4
(*b*)	6·0	2·7	2·4	2·0	2·6	2·5

With one exception (Coke No. 3, cube *b*), the loss by abrasion of the longitudinal face was always greater than that of the transverse face. In successive tests the actual loss from each face became less (though the order of abradability of the several cokes, as indicated by the losses, remained substantially the same). Averages of the tests, and the order of abradability indicated by the averages, are as follows (Table III) :—

Table III.—Comparison of Abradability of Longitudinal and Transverse Coke Surfaces

Coke No.	Abrasion Loss.			Order of Abradability.		
	Average Longitudinal Face.	Average Transverse Face.	Mean.	Longitudinal Face.	Transverse Face	Mean.
1	6·5	3·0	4·8	1	2	1
2	3·8	1·0	2·9	3	7	3
3	4·7	4·2	4·5	2	1	2
4	3·3	2·3	2·8	4	3	4
5	1·5	1·7	1·6	7	5	7
6	2·0	1·3	1·7	6	6	6
7	2·9	2·1	2·5	5	4	5

These results emphasise the difficulty of obtaining representative samples of cokes for tests of this character. Nevertheless, if a sufficient number of tests on each coke are made, the relative abradability values appear to be reliable and the test is of undoubted value for studying such problems as the effect of pressure on the abrasion loss.

The Effect of Pressure on Abrasion Loss.—By altering the position of the balance-weight in the true abrasion test apparatus (see Fig. 26), it was possible to obtain thrusts of 4·3, 7·5 and 11 lb. on the coke surfaces (4 sq. in.), corresponding with pressures of approximately 1, 2 and 3 lb. per sq. in. The results of several series of tests, which need not be detailed, showed that increase in the pressure did not increase the loss by abrasion, a point of importance when considering the extent to which the drum test described in Chapter VI can be regarded as a true test of abradability.

CHAPTER VII

THE HARDNESS OF COKE

The "impact hardness" or the true hardness of coke, as we have defined it, is its power of resistance to breakage on dropping. It has been shown in Chapter II that the amount of breakage of coke during handling is proportional to the total height through which it is dropped. Each time that coke is dropped, breakage occurs and breeze is formed.

The "shatter test," now to be described, has been devised to afford a measure of the liability of coke to form breeze when it is dropped, four 6-ft. drops being assumed to reproduce sufficiently closely: (1) The fall from the oven on to the coke bench or car; (2) the loading into a wagon at the coke plant; (3) the loading into a hopper at the blast-furnace plant; and (4) the fall to the charge-level in the blast-furnace. If the coke as discharged from an oven were all over 2-in. size, and if the aggregate height through which it dropped before it reached the charge level of the blast-furnace were 24 ft., the shatter test would give a close estimate of the proportion of breeze in the charge at the blast-furnace. In practice, at the ovens the breeze formed when the coke drops on to the bench is usually screened out, whilst at the blast-furnace plant the height of the drops at the hopper and on to the charge may be more or less than 6 ft., according to their levels. The shatter test does not, therefore, always give a correct measure of the amount of breeze to be expected from a coke at the blast furnace. It should be regarded merely as showing the liability of a coke to produce breeze when handled in a specified way.

THE SHATTER TEST

The origin of the shatter test is obscure. Kinney and Perrott (*J. Ind. Eng. Chem.*, 1922, **14**, 926) ascribe it to Croxton. It is said to have been used at coke-oven plants in America for more than twenty years. One of the earliest descriptions of the test is probably that given by Belden (U.S. Bureau of Mines Tech. Paper No. 50, 1913) of the apparatus then used by the United States Bureau of Mines. An improved apparatus, described by Kinney and Perrott (*loc. cit.*), was later adopted as a tentative standard by the American Society for Testing Materials (*A.S.T.M. Proc.*, 1922, **22**, 822), to be used with four screens, 2-in., 1½-in., 1-in. and ½-in. Finally, the shatter test for coke was classified as "standard" by the A.S.T.M. (1927, A.S.T.M. Standards, Part II, Non-metallic Materials. Serial Designation: D 141–23).

A standard specification of the shatter test has now been adopted by the Midland, Northern and Scottish Coke Research Committees, and recommended for general use in Great Britain, as follows :

(i) *Apparatus.* The shatter test apparatus * shall consist of a box 18 in. in width, 28 in. in length, and approximately 15 in. in depth, supported above a rigidly mounted cast-iron or steel plate, not less than ½ in. in thickness, and not less than 38 in. in width and 48 in. in length. The inside of the bottom of the box when in its highest position shall be 6 ft. above the plate. The bottom of the box shall consist of two doors hinged lengthways and latched so that they will swing open freely and not impede the fall of the coke. Boards about 8 in. in height shall be placed around the plate so that no coke is lost. To minimise the breakage of coke, which might otherwise occur while placing the sample in the box, the box shall

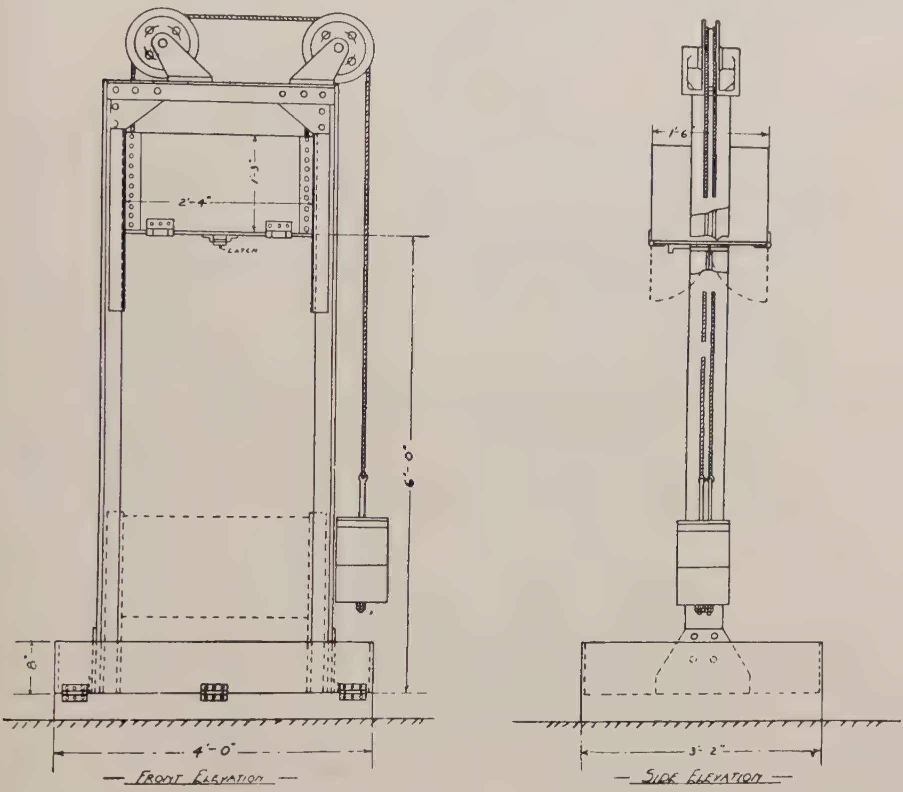


FIG. 27.—Standard Shatter Test Apparatus.

---

* The essential dimensions of the shatter test apparatus are those given by the American Society for Testing Materials in "Standard Method of Shatter Test for Coke," Serial Designation: D141–23 (A.S.T.M. Standards, 1927, Part II, Non-metallic Materials, p. 571).

be so suspended that it can be lowered to a convienent level for filling. A convenient form of shatter test apparatus is shown in Fig. 27.

(ii) *Screens.* For determining the breakage of the coke sample, square-mesh screens with the following openings shall be used: 2 in., 1½ in., 1 in. and ½ in. These screens should be machine stamped from mild-steel plates * with a limit of error of 1/32 in.

(iii) *Procedure,* Fifty pounds † of coke all over 2 in. shall be placed in the box of the shatter test apparatus, the coke levelled, the box raised and the coke dropped on to the plate. The box shall be lowered and all the coke shovelled into it indiscriminately, care being taken to avoid breakage. The box shall then be raised and the coke again dropped. When the coke has thus been dropped four times in all, it shall be screened by hand in such a way that any piece which can pass through the screen in any position shall be counted as

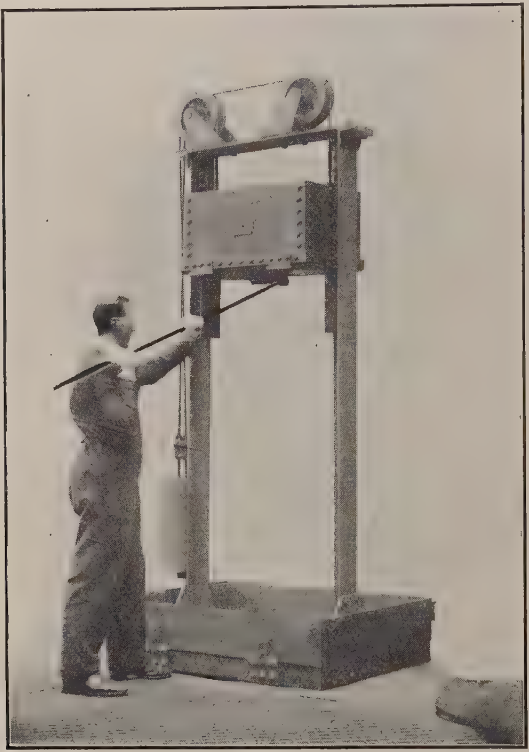


Fig. 28.—Standard Shatter Test Apparatus in Use.

---

* Obtainable from Messrs. G. A. Harvey & Co. (London), Ltd., Woolwich Road, S.E.7.

† If for any reason the shatter test cannot be made with a true average sample of the original coke over 2 in., the grading of the coke taken for shatter test should preferably be such that the weight-ratio of the 4-in., 3-in. and 2-in. grades is that found in a preliminary size analysis of the original coke.

undersize, and the weights of coke of each grade shall be determined to the nearest ounce.

(iv) *Statement of Results.* At least three tests shall be made and the results stated as percentages (given to one decimal place) remaining on 2-in., 1½-in., 1-in. and ½-in. screens. The shatter indices reported shall be the average values of the percentages retained on the 2-in. and 1½-in. screens, and shall be given to the nearest whole number only.

A single figure shall be understood to be the 2-in. index unless otherwise stated. In future, the 1½-in. figure shall invariably be given in addition to the 2-in. figure by stating the shatter indices in the form 74/86, where the figures are the 2-in. and 1½-in. indices respectively.

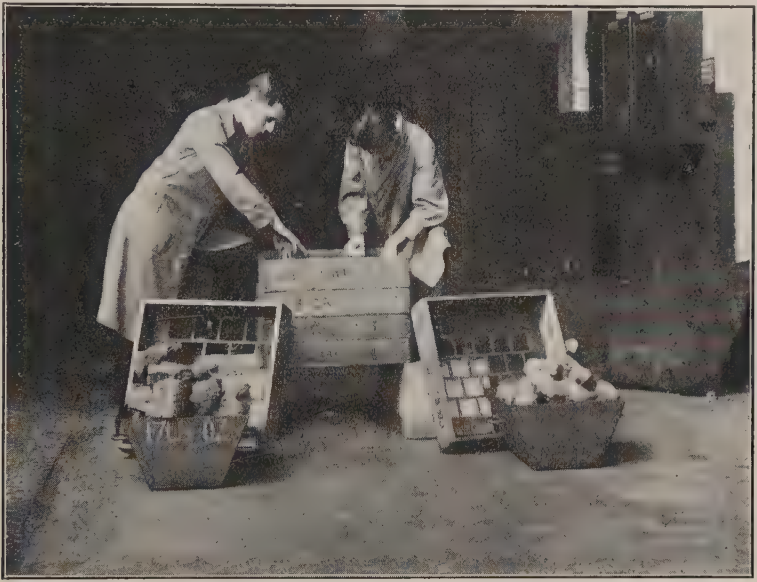


FIG. 29.—Screening after Shatter Testing, showing Type of Screen and Method of Handling.

Where possible, the statement of the shatter indices shall be accompanied by a brief description of the coke; for example, as "blocky coke," "prismatic coke," "narrow oven coke," "compressed-charge coke," "beehive coke."

(v) *Tolerated Deviation.* If the average deviation of the individual results from their average exceeds 3·0 and 2·0 at the 2-in. and 1½-in screens, respectively, the corresponding shatter indices shall be marked with an asterisk, and if it is desired to base any conclusion or to take any action upon the result, a further series of at least two tests shall, if possible, be made and the results thereof averaged with those of the original series.

Fig. 28 shows the standard apparatus in use.

In the A.S.T.M. standard method of shatter testing, square-mesh sieves are specified without reference to their construction. We have found that the apertures of screens of crimped wire, such as can be obtained from ironmongers, are frequently inaccurate in size, whilst enlargement of some of the apertures of the larger sizes of screens occurs with continued use. We have therefore adopted screens made from mild-steel plates, the apertures of which, being machine stamped, are uniform in size. The error in size does not exceed $\frac{1}{32}$-in. For regular use, including the size analysis of the coke as received, we find that a set of 4-in., 3-in., 2-in., 1½-in., 1-in. and ½-in. screens, each 2 ft. square, is convenient. The larger-sized apertures are staggered to avoid weakening the screen. The thickness of the plates is $\frac{3}{16}$-in. for the 4- to 1½-in. screens and ⅛-in. for the smaller sizes. Fig. 29 illustrates such screens in use, the method of hand-screening the larger sizes, to obtain true screening efficiency, being indicated. The top screen is shaken to allow the smallest pieces to pass through. The pieces that are obviously larger than the screen mesh are placed in a tared box and the doubtful pieces are screened by hand.

Duplication of Results of Shatter Test.—An important consideration is the ability of the shatter test to yield duplicate results with the same coke. The extent to which variation in the results is to be expected can be gauged from the records, in Table XXVIII, of successive tests on representative cokes. The proportions of the cokes remaining on 2-in. and 1½-in. screens after shatter testing (the so-called 2-in. and 1½-in. "shatter indices") are given in this table.

Considerable differences are found, on occasion, between successive tests. There is, for example, a difference as high as 12·0 between the maximum and minimum values for the 2-in. index for coke No. 6. For this reason, the result of a single shatter test is insufficient to specify the hardness of a coke. When, however, the mean values for three successive tests are compared with the averages for a number, say 8 or 9, the deviation is not great. For the series of cokes to which Table XXVIII relates it is at most 3·1 for the 2-in. and 1·1 for the 1½-in. index. The average deviation for all four cokes is 1·5 for the 2-in. and 0·5 for the 1½-in. index. It will be noted that the agreement between the results of successive tests is uniformly better for the 1½-in. than for the 2-in. index, even taking into account the smaller range of values for the 1½-in. index.

The agreement between the results of successive tests is usually better the harder the coke. The average deviation of each determination from the mean of three is recorded, for a number of cokes, in Table XXIX.

As a measure of hardness, it is desirable to record the mean of at least three shatter tests for the harder and at least five for the weaker cokes. The use of the 1½-in. index reduces the experimental deviation for most cokes to less than 1·5, and, for this reason, is to be preferred.

TABLE XXVIII.—Duplication of Results of Shatter Testing.

Test No.	Coke No. 1 (S. Wales).				Coke No. 6 (Durham).				Coke No. 3E (VII) (Yorks.).				Coke No. 3E (IV) (Yorks).			
	2-in.	1½-in.	Mean. 2-in.	Mean. 1½-in.	2-in.	1½-in.	Mean. 2-in.	Mean. 1½-in.	2-in.	1½-in.	Mean. 2-in.	Mean. 1½-in.	2-in.	1½-in.	Mean. 2-in.	Mean. 1½-in.
1	96·5	97·5	93·7	97·2	92·1	94·8	88·9	94·1	80·5	90·2	78·6	90·0	71·4	85·2	69·9	82·3
2	93·0	97·0			90·6	93·8			74·8	89·4			69·6	81·4		
3	91·5	97·0			84·1	93·8			80·6	90·3			68·8	80·4		
4	95·5	97·5	93·2	97·3	85·1	91·3	83·8	92·3	79·4	89·5	77·6	88·4	63·6	81·4	66·5	82·3
5	89·5	96·5			86·1	93·3			75·5	87·3			69·6	82·6		
6	94·5	98·0			80·1	92·3			77·8	88·5			66·2	83·2		
7	96·5	97·0	95·2	97·2	83·1	92·3	84 1	93·0	76·0	88·6	75·0	88·8	72·4	80·4	70·9	80·7
8	94·5	97·5			85·1	93·8			74·0	89·0			67·0	79·4		
9	94·5	97·0			—	—			—	—			73·4	82·2		
Average . . .	93·9	97·2			85·8	93·2			77·3	89·1			68·9	81·8		
Maximum . . .	96·5	98·0			92·3	94·8			80·6	90·3			73·4	85·2		
Minimum . . .	89·5	96·5			80·1	91·3			74·0	87·3			63·6	79·4		
Range . . .	7·0	1·5			12·0	3·5			6·6	3·0			9·8	5·8		

TABLE XXIX.—AVERAGE DEVIATION OF EACH RESULT OF SHATTER TEST FROM MEAN OF THREE

Number of Cokes Tested.	Range of Shatter Index (2-in.).	Average Deviation		
		2-in. Index.	1½-in. Index.	1-in. Index.
17	Over 80	1·7	0·8	0·4
32	80–70	2·3	1·1	0·4
37	70–60	2·2	1·6	0·6
21	60–50	2·8	1·8	1·0
9	Under 50	2·5	1·8	0·7
116	General average deviation.	2·3	1·4	0·6

The Significance of Different Shatter Indices.—When carrying out a shatter test, it is clear that an "index" of hardness can be assigned to a coke with respect to each of the screens used to determine the proportions of different-sized pieces remaining after shattering. Information as to the significance of each "index" obtainable in this way was sought by carrying out shatter tests on cokes of over 4-in., 4 to 3-in. and 3 to 2-in. sizes, using screens having 4, 3, 2, 1½, 1 and ½-in. apertures. Some of the results of such tests for a very good (South Wales) and a poor (Derbyshire) coke are recorded in Table XXX.

TABLE XXX.—SHATTER TESTS ON COKES OF DIFFERENT SIZES

Coke.	Size of Coke.	Percentage remaining, after Shatter Test, on :					
		½-in.	1-in.	1½-in.	2-in.	3-in.	4-in.
No. 14 (S. Wales)	Over 4-in.	98·8	98·0	96·2	89·6	Not determined.	
		98·6	97·4	94·1	84·3	64·1	36·4
		98·8	98·3	97·3	91·8	81·7	58·5
	4 to 3-in.	98·9	98·1	95·8	86·8	71·3	—
		99·1	98·4	96·9	91·3	69·3	—
		98·9	98·2	95·3	88·3	70·1	—
		98·8	98·1	96·5	91·1	60·9	—
	3 to 2-in.	98·6	98·1	95·4	85·9	—	—
		99·0	98·5	96·3	86·5	—	—
		99·1	98·7	96·8	83·3	—	—
		99·1	98·6	95·7	83·4	—	—
Range : Max. to Min.		0·5	1·3	3·2	8·5	20·8	—
No. 15 (Derbyshire)	Over 4-in.	96·0	83·3	57·3	43·0	27·8	9·4
	4 to 3-in.	97·1	83·2	66·0	53·4	30·6	—
		96·8	83·5	59·9	39·0	11·0	—
		97·0	85·4	66·2	47·0	24·0	—
	3 to 2-in.	97·2	84·3	63·0	45·6	—	—
		97·2	82·6	63·1	46·7	—	—
		97·4	86·4	67·4	45·4	—	—
Range : Max. to Min.		1·4	3·8	10·1	14·4	19·6	—

If the percentage of coke remaining on the ½-in. screen after shattering were taken as the index of hardness, the two cokes would not be regarded as differing much in hardness, whereas an index based on the percentages of the cokes remaining on any of the other screens would place them widely apart. It has been found during the course of testing many cokes that the ½-in. index rarely falls below 97 except when the coke is readily abraded. It is therefore of little value as a measure of hardness, but it can be used as a rough measure of abradability. Cokes liable to loss by abrasion have not the same coherence as normal cokes, and small fragments are readily knocked off the pieces by impact. As showing the applicability of the ½-in. index as a measure of abradability, it may be mentioned that of the fifteen cokes listed in Table XXVII (Chapter VI) as being easily abraded, only three (Nos. 22A, B and C) had ½-in. shatter indices greater than 97. On occasion cokes that are not readily abraded have a ½-in. shatter index less than 97. Such cokes are found to have irregular structures due, for example, to sponginess at the centre-of-oven ends or to abnormally close and frequent fissuring.

Taking the screen analysis of the two cokes given in Table XXX, the choice of shatter index, other than the ½-in., as the index of hardness would seem to be one of convenience only. Fig. 30 represents the various shatter indices for a number of cokes, plotted with rectangular co-ordinates.* It will be seen that nearly straight line graphs connect the indices from the 1-in. upwards for the poor and medium quality cokes (Nos. 15 and 16), from the 1½-in. upwards for the good quality coke (No. 17A), and from the 2-in. upwards for the best quality coke (No. 14). For practical purposes, the graphs can be considered to be linear from the 1½-in. index upwards for all cokes, and one index—the 2-in., for example —can be calculated roughly from another, say the 1½-in. The experimental variations in the size analyses between shatter tests on the same coke are greater, however, the larger the aperture of the screen, so that the calculation of the 4-in. index, for example, from the 1½-in. is the merest approximation.

Most interest attaches to the 1-in., 1½-in. and 2-in. indices. In Table XXIX it was shown that the average deviation was less the smaller the screen index. An examination of a large number of results shows the 1-in. index to be unsuitable, however, because of the small range of values provided by it. For example, out of a series of 108 cokes tested 81 have differed by eight points only and 67 by but six points. Such differences are too small to allow of proper discrimination, for general purposes, between a number of cokes. Nevertheless, the 1-in. index is a reliable measure of the hardness of a coke, and a record of it affords a useful check on the more generally useful 1½-in. and 2-in. indices which, as will be shown

---

* In early tests, a supposedly 2-in. screen was used the apertures of which were subsequently found to be nearly 2¼-in. Correction has been made for this.

UNIVERSITY
COLLEGE
LIBRARY
NOTTINGHAM

presently, may occasionally give false values for the "hardness" of cokes.

The ranges provided by the 1½-in. and 2-in. indices are wider. It is important to consider these ranges in relation to the average deviations from the means of the test results for both indices. For this purpose, it is necessary to consider the results for a large number of cokes ranging in close sequence from high to low index. Such a series, for both the 2-in. and the 1½-in. indices, is listed in Table XXXI. In this series, the maximum interval (with one exception,

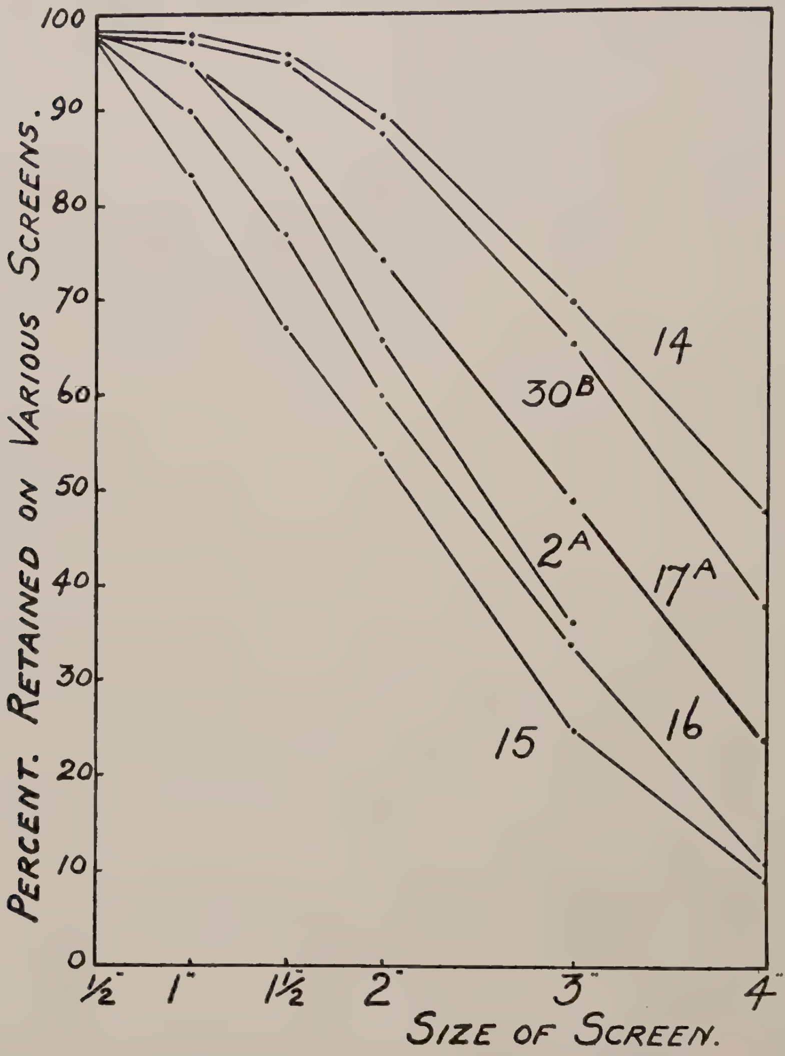


FIG. 30.—Graph showing Relationship between Shatter Indices at Different Screens for a Number of Representative Cokes.

between 86·3 and 84·5) between any two cokes within the range 89·0 and 51·2 is 1·3. Above 89·0 there is an interval of 2·2, and below 51·2 the next interval is 1·4. We take as the normal range of the 2-in. index for oven cokes tested by us the interval 89·0 to 51·2, or 37·8 points. For the 1½-in. index, the corresponding range is between 96·5 and 65·0, or 31·5 points.

The ratio between the accepted ranges for the two indices is 1·20, or about 5/4. The average deviation from the mean of three test results is 2·3 for the 2-in. and 1·4 for the 1½-in. index. The ratios between the deviations and the accepted ranges are: for the 2-in. index, 16·4; and for the 1½-in. index, 22·5. The 1½-in. index is, therefore, the more reliable so far as the majority of the cokes tested by us are concerned. These have been mainly from Yorkshire, Derbyshire and Lancashire, but they include several South Wales, Durham and Cumberland cokes.

Table XXXI.—Shatter Indices of a Series of Cokes

2-in. shatter indices.			1½-in. shatter indices.		
93·1	73·1	62·2	97·0	87·2	78·4
91·2	73·1	61·8		86·7	78·4
	72·3	61·7	96·5	86·6	78·3
89·0	72·2	61·3	96·1	86·3	78·1
88·6	72·2	60·8	95·9	85·8	78·1
88·6	72·1	60·5	95·7	85·6	78·1
88·5	71·9	60·4	94·8	85·5	77·7
87·4	71·3	60·2	94·2	85·2	77·2
87·0	71·2	59·4	92·7	84·6	76·5
86·5	71·2	59·3	92·7	84·6	76·0
86·3	69·9	58·9	92·3	84·5	75·3
84·5	69·3	58·4	92·3	84·4	75·2
84·0	69·2	58·0	92·2	84·3	74·6
82·8	69·1	57·8	92·2	83·8	74·1
82·7	69·0	57·7	91·8	83·2	73·7
81·5	68·6	57·1	91·3	83·0	73·6
81·2	68·5	56·7	90·9	82·9	73·5
80·3	68·4	56·6	90·8	82·8	72·5
80·0	67·8	56·0	90·3	82·6	72·2
79·8	67·8	55·3	90·3	82·6	72·2
79·8	67·4	54·8	90·1	82·4	72·1
79·5	67·3	53·6	90·0	82·4	71·8
79·4	67·3	53·6	90·0	82·3	71·3
78·9	66·9	53·6	89·8	81·9	69·7
78·9	66·4	53·2	89·7	81·8	69·3
78·6	66·3	52·6	89·5	81·7	69·0
78·3	66·1	52·3	89·2	81·6	68·8
78·2	66·0	52·0	88·6	81·5	68·7
76·9	65·6	51·2	88·6	81·0	68·0
76·7	65·2		88·4	80·9	67·8
76·6	64·1	49·8	88·4	80·8	67 1
76·1	64·1	48·9	88·2	80·7	66·6
75·5	63·6	46·5	88·2	80·7	65·0
75·4	63·4	46·5	88·1	80·2	
74·4	63·3	43·7	88·1	79·9	64·3
74·4	63·1	41·9	88·0	79·1	64·1
74·3	62·5	41·8	87·6	79·0	64·0
74·1	62·3	36·2	87·3	78·9	61·9
73·5	62·2	35·0	87·2	78·7	59·9
73 3			87·2		

The linear relationship that exists between the different shatter indices can be expressed in a different way for the 1½-in. and 2-in. values. On plotting, for a number of cokes, the values for the 1½-in. index against those for the 2-in. index, the points of intersection lie near a straight line, the equation of which is $y = 0{\cdot}75x + 30$, y being the 1½-in. and x the 2-in. shatter index (Fig. 31). For cokes made in fast-coking, narrow ovens, however, the 2-in. shatter index is abnormally low in comparison with the 1½-in. index. The value for y is therefore higher than that calculated from the equation. Typical examples are given in Table XXXII for the shatter tests of two cokes made from the same coal, one in a 14-in. and the other in a 21-in. oven, both top-charged.

TABLE XXXII.—COMPARISON OF SHATTER INDICES OF COKES MADE IN OVENS OF DIFFERENT WIDTHS

Coke.	No. 29C (S. Yorks.).	No. 29B (S. Yorks.).
Width of Oven	14-in.	21-in.
Shatter Index : 2-in. .	65·6	74·1
,, ,, 1½-in. .	85·2	86·7
,, ,, 1-in. .	95·2	94·1

Whilst the 1½-in. and 1-in. indices are nearly the same for the two cokes, the 2-in. index for the coke made in the 14-in. oven is abnormally low. The reason for this has been traced to the small cross-sectional area of the coke produced in modern narrow ovens, a condition leading to the formation of much 1½-in. to 2-in. coke on shattering. Since the coke made in modern narrow ovens in America and Germany has not been found in practice to be inferior to that made in the older types of wide ovens, but rather the reverse, it can reasonably be concluded that the 1½-in. shatter index more fairly represents the blast-furnace value of such cokes than does the 2-in. index. In the same way, the 1½-in. index best assesses the value of most beehive oven cokes and by-product oven cokes made from compressed charges and from certain blends. These, owing to their prismatic formation, yield a higher proportion of 1½-in. to 2-in. sizes on shattering than do the blockier kinds of cokes.

The liability for prismatic cokes to yield abnormal figures for the 2-in. shatter index is displayed by the following tests. From each of seven cokes made from compressed charges, pieces sized between 3 and 2¼ in. and between 2¼ and 2 in. were collected and subjected to shatter test in the usual way. The 3- to 2¼-in size can be regarded as representing "blocky" and the 2¼- to 2-in. size as representing "prismatic" coke. From each make of coke, the two types would be of approximately the same quality. The results of the tests are recorded in Table XXXIII.

Of these cokes, Nos. 17J and 17L were Yorkshire and Nos. 28A, 28B and 28E Derbyshire. With six out of the seven, the "blocky" coke gave a higher 2-in. shatter index than the "prismatic," whereas

TABLE XXXIII.—COMPARISON OF SHATTER INDICES OF "BLOCKY" AND "PRISMATIC" COKES OF THE SAME QUALITY

No. of Coke.	Size (In.).	Shatter Indices.		
		1-in.	1½-in.	2-in.
17J i	3 to 2¼ (Blocky)	92·3	82·4	72·4
	2¼ to 2 (Prismatic)	94·2	85·9	63·3
17J ii and iii	3 to 2¼	94·3	85·0	75·7
	2¼ to 2	92·5	76·6	60·6
17L i and ii	3 to 2¼	94·1	83·3	72·1
	2¼ to 2	95·1	84·6	65·8
17L ii and iii	3 to 2¼	95·0	84·5	74·6
	2¼ to 2	95·6	86·1	73·3
28A	3 to 2¼	79·2	62·8	42·2
	2¼ to 2	79·6	61·7	43·1
28B	3 to 2¼	88·6	75·4	61·3
	2¼ to 2	87·9	73·9	47·6
28E	3 to 2¼	85·3	74·7	63·2
	2¼ to 2	85·7	73·6	60·0

the 1½-in. index did not vary much. The figures can be summarised as follow:

	Average Shatter Indices.	
	1½-in.	2-in.
Blocky cokes (3- to 2¼-in.)	78·3	65·9
Prismatic cokes (2¼- to 2-in.) . . .	77·5	59·1

Taking the line $y = 0{\cdot}75x + 30$ as representing the ideal relationship between the 1½-in. and 2-in. shatter indices, it is found that for normal cokes, of which a large number have been tested, the points representing the 1½-in. index plotted against the 2-in. index lie between two straight lines, $y_1 = 0{\cdot}6x_1 + 43$ and $y_2 = 0{\cdot}9x_2 + 15$, such as are drawn in Fig. 31. When the points fall on the centre line ($y = 0{\cdot}75x + 30$), the 2-in. shatter index gives as reliable a measure of the hardness of the coke as does the 1½-in. index; but when they fall on or near either the upper or the lower line, the 1½-in. index is the better. Points near the lower line generally represent "freak" cokes, made by blending a poorly coking coal with non-coking material, which are abnormally blocky but friable.

To the reasons already given for our preference for the 1½-in. shatter index over the 2-in.—namely (1) the smaller variations between repeat tests, and (2) the failure of the 2-in. index to assess correctly either prismatic or abnormally blocky cokes—may be added a third: The minimum size of coke pieces of value in blast-furnace practice is certainly not more than 1½-in., and there is no evidence that 2-in. pieces are preferable to 1½-in. A better measure of the useful hardness of a coke is therefore given by the 1½-in. shatter index.

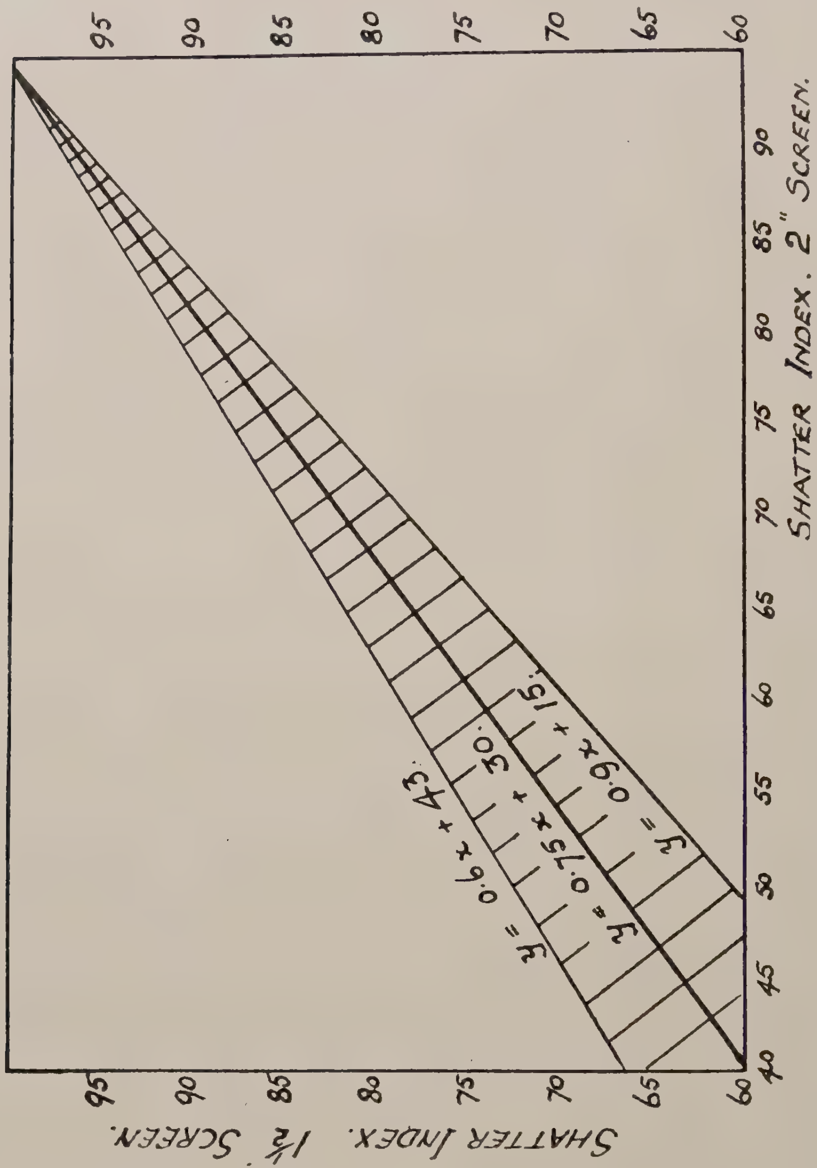


FIG. 31.—Graph showing Relationship between 2-in. and 1½-in. Shatter Indices for Series of Cokes.

In the past, the 2-in. shatter index alone has been largely used, though the A.S.T.M. standard method of test (*q.v.*) specifies size analysis, after shattering, with 2-in., 1½-in., 1-in. and ½-in. screens. The use of all four screens is certainly desirable, the first three to indicate the hardness of the coke and the fourth to give a rough measure of its abradability. The 2-in. index should be determined for comparison with existing data, the 1½-in. as the most serviceable hardness index and the 1-in. as a check on the latter should the coke prove abnormal.* The best method of recording the shatter indices is as whole numbers for the percentages of the coke remaining on both the 2-in. and 1½-in. screens, thus: Coke No. 14, 87/96; coke No. 15, 46/62.

The Effect on the Shatter Index of the Size of Coke Used for Test.—The results of tests illustrating the effect of using over 4-in., 4- to 3-in. and 3- to 2-in. sizes of two varieties of cokes for the shatter test have been recorded in Table XXX. Further results are given in Table XXXIV.

TABLE XXXIV.—AVERAGE RESULTS OF SHATTER TESTS ON COKE OF DIFFERENT SIZES

Coke.	Size.	Number of Tests Made.	Shatter Indices.				
			1-in.	1½-in.	2-in.	3-in.	4-in.
No. 14 (S. Wales)	On 4-in.	3	97·9	95·9	88·6	72·9	47·4
	4- to 3-in.	4	98·2	96·1	89·4	67·9	—
	3- to 2-in.	4	98·5	96·0	84·8	—	—
No. 43 (S. Wales)	On 4-in.	4	98·0	95·9	91·5	67·9	47·4
	4- to 3-in.	3	98·4	96·5	89·1	62·4	—
	3- to 2-in.	1	98·8	97·3	91·4	—	—
No. 30B (Durham)	On 4-in.	3	97·4	94·8	87·4	65·5	38·2
	4- to 3-in.	3	97·6	95·4	87·7	57·5	—
	3- to 2-in.	2	98·0	95·3	88·3	—	—
No. 2A (Durham.)	On 3-in.	3	94·7	83·7	66·2	36·5	—
	3- to 2-in.	4	95·3	84·0	65·0	—	—
No. 18A (S. Yorks.)	On 4-in.	2	89·8	76·4	60·7	37·7	19·5
	4- to 3-in.	2	91·6	78·2	60·6	24·6	—
	3- to 2-in.	2	92·5	79·3	56·2	—	—
No. 3B (S. Yorks.)	On 4-in.	2	91·4	78·5	61·4	29·4	11·8
	4- to 3-in.	2	93·1	80·3	64·3	32·8	—
	3- to 2-in.	2	92·5	79·7	60·7	—	—
No. 16 (Lancs.)	On 4-in.	3	90·2	77·2	59·8	33·9	10·9
	4- to 3-in.	3	92·4	81·2	58·5	29·1	—
	3- to 2-in.	3	93·4	83·0	65·0	—	—
No. 15 (Derby.)	On 4-in.	1	83·3	57·3	43·0	27·8	9·4
	4- to 3-in.	3	84·0	64·0	46·5	21·9	—
	3- to 2-in.	3	84·4	64·5	45·9	—	—

With decreasing size of the coke tested, there is, generally, a small increase in the 1-in. and 1½-in. shatter indices, whilst the 2-in. index varies in an irregular manner. Cokes Nos. 15 and 16 were made from compressed charges, and these show considerable differences in the 1½-in. index as the size of coke tested was decreased, the reason being that the larger pieces were much fissured (see Plate XXVI, where the structures of these two cokes are compared with those of Nos. 43 and 30B). With the cokes of high shatter index, the larger pieces are almost as hard as the smaller, but with the weaker, more extensively fissured, cokes the smaller sizes are the harder.*

---

* See appendix to this chapter.

The Effect on its Hardness of the Position of Coke in the Oven.—The extent to which the location of coke in the oven affects its hardness has been determined by one of the members of the Midland Coke Research Committee, Mr. C. P. Finn. Samples were taken along the middle of the length of the oven at three different horizons, namely, at the top, at the sole and midway between the two. Such samples were taken from a number of ovens coking the same coal (90 per cent. Parkgate and 10 per cent. Barnsley) and tested, with the results recorded in Table XXXV.

TABLE XXXV.—THE EFFECT ON ITS HARDNESS OF THE POSITION OF COKE IN THE OVEN (HORIZONTALLY FLUED)

Oven No.	Oven Lining.	Coking Time (Hours).	Shatter Index (2-in.).			
			Top of Charge.	Middle of Charge.	Bottom of Charge.	Average.
40	Silica	23	81·5	72·7	50·0	68·1
41*	,,	23	78·0	70·6	65·0	71·4
52	Semi-silica	28½	78·0	76·2	61·5	71·9
55	,,	27	75·7	73·0	70·5	73·1
49	,,	29	77·0	72·2	64·6	71·3
44	,,	28	74·7	69·5	62·3	68·8
Average for semi-silica ovens .			76·3	72·7	64·7	71·3

* Uncrushed coal. Crushed coal was used in all the other ovens.

The ovens were horizontally-flued waste-heat ovens. Typical flue temperatures, measured by an optical pyrometer (disappearing filament), are given in the table that follows.

Although only the 2-in. shatter index was determined (one test only), the results are sufficiently definite to show that the coke at the top of the oven was the hardest and that at the bottom the weakest, a result in agreement with our knowledge of the variations in the degree of fissuring of coke dependent on its position in the oven (see p. 39). The average of the twelve tests of coke taken

---

* It follows from these considerations that the "cracking," at the ovens, of the larger pieces of the poorer cokes would reduce their liability to form breeze during subsequent handling and transport. Such cracking would not be equivalent in its effects to the dropping and rough handling discussed in Chapter II, but some breeze would be formed.

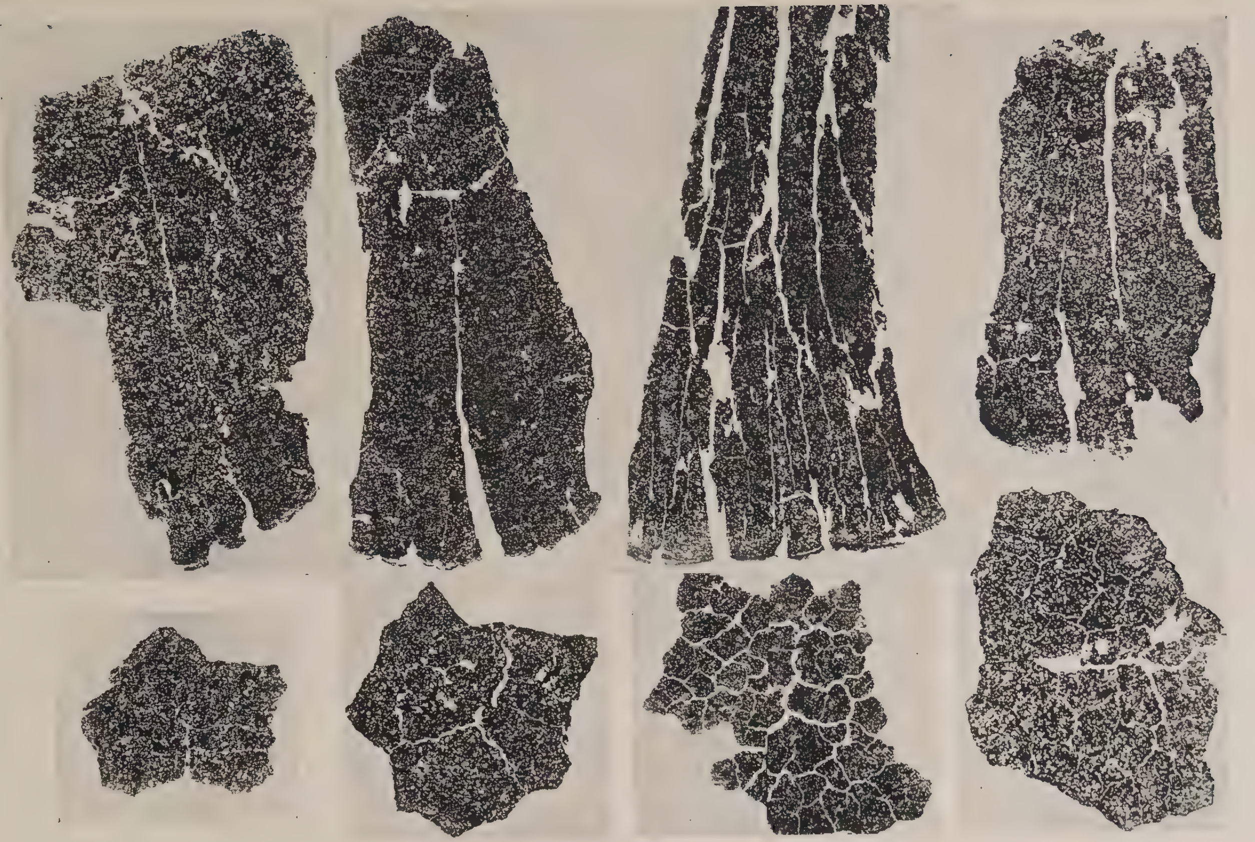


PLATE XXVI.—Structure of Cokes; to illustrate the Relationship between the Hardness of Different Coke Sizes and the Degree of Fissuring.

[*To face p.* 108.

Oven.	Flue No.	Max. Temp.	Min. Temp.	Average.	Average for Oven.
No. 44 (Semi-silica) .	1 (Top)	960°	820°	923°	992°
	2	990	910	947	
	3	1100	960	1034	
	4	1100	1000	1063	
No. 40 (Silica) . .	1	1190*	980	1095	1103°
	2	1080	1020	1056	
	3	1140	1055	1102	
	4	1180	1130	1158	

* Local overheating.

from the semi-silica ovens (71·3) was almost identical with the result of a routine test of the same coke on average samples taken from four different semi-silica ovens (70·5).

The necessity for obtaining fair average samples, from the top, middle and bottom of the oven, for shatter tests is evident from these results. Their significance should not, however, be overestimated. In particular, it should be noted that the main difference in hardness is between the coke from the top of the oven and that near the sole, which latter represents but one-eighth of the oven charge. In this connexion it may be suggested that some of the low results occasionally obtained during successive routine tests of a coke are due to an undue proportion of oven-sole coke in the sample. The difference in hardness (2-in. index) between the coke from the top of the oven and that from the middle is only about 3 per cent. There is little doubt that, had the 1½-in. indices been recorded, they would have shown an even smaller difference.

Similar tests have been made on samples of coke taken from a vertically-flued oven coking the same coal. The results are recorded in Table XXXVI.

TABLE XXXVI.—THE EFFECT ON ITS HARDNESS OF THE POSITION OF COKE IN THE OVEN (VERTICALLY FLUED)

Oven No.	Coking Time (Hours).	Shatter Index (2-in.).			
		Top of Charge.	Middle of Charge.	Bottom of Charge.	Average.
17*	34	75·8	68·4	64·3	69·5
35†	84	(i) 71·0 (ii) 77·7	72·4	70·7	72·9

* Uncrushed coal. † Oven heated from one side only.

The second " top of charge " sample from oven No. 35 was taken at a level 1 ft. below the top. It is easy to understand why heating the oven from one side only should produce harder and more uniform coke, for the coke at the oven sole would be " double-fractured " on one half only.

Tests of cokes made in horizontally flued ovens from a better coking coal (Halifax Soft) are recorded in Table XXXVII. The differences in hardness of the coke samples taken at different levels in the oven are not so marked as with the poorer coking coal.

TABLE XXXVII.—THE EFFECT ON ITS HARDNESS OF THE POSITION OF COKE IN THE OVEN (HORIZONTALLY FLUED)

Oven Lining.	Average Flue temp. °C.		Shatter Index (2-in.).			
	Top.	Bottom.	Top of Charge.	Middle of Charge.	Bottom of Charge.	Average.
Semi-silica	970	1010	84·0	81·5	82·0	82·5
Silica	1040	1190	83·0	81·5	82·5	82·3

Another of the members of the Midland Coke Research Committee (Mr. G. T. Purves) has compared the hardness of samples of coke taken from the top, middle and bottom of ovens. Two different coking slacks were used, the one poorly caking and the other strongly caking, 14-in. and 21-in. ovens being used for both. The results are recorded in Table XXXVIII.

TABLE XXXVIII.—THE EFFECT ON ITS HARDNESS OF THE POSITION OF COKE IN THE OVEN (VERTICALLY FLUED)

Oven Width.	Coal.	Shatter Index (2-in and 1½-in.).					
		Top of Charge.		Middle of Charge.		Bottom of Charge.	
		2-in.	1½-in.	2-in.	1½-in.	2-in.	1½-in.
21-in.	Poorly-caking	69	81	67	79	58	76
	Strongly-caking	81	89	73	88	45	71
14-in.	Poorly-caking	69	86	67	84	63	79
	Strongly-caking	76	87	65	86	62	82

These results, whilst confirming the weakness of the oven-sole coke as compared with that of the rest of the charge, show that there is not much difference in hardness, as judged by the 1½-in. index, between the coke at the top and that at the middle of the oven.

The Effect on its Hardness of the Early Treatment of Coke.—The results of shatter tests on coke of different sizes (recorded in Tables XXX and XXXIV) suggest that a test on a given coke carried out at the blast-furnace plant might give a higher result than one at the coke-oven plant, for the reason that, during the course of handling and transport between the two plants, many of the larger-sized lumps of coke would be broken down into smaller pieces, which would be more resistant to shattering. We have tested this suggestion by carrying out re-tests on coke that had already been subjected to shatter test. The results are recorded in Table XXXIX.

TABLE XXXIX.—THE RESULTS OF SHATTER TESTS ON SHATTERED COKE

Coke.		Index.		
		2-in.	1½-in.	1-in.
No. 39 (S. Wales)	Shatter Index on receipt	89·8	96·9	98·5
	,, ,, ,, re-test	93·7	97·9	98·8
No. 40B (Lancs.)	Shatter Index on receipt	80·4	89·3	96·0
	,, ,, ,, re-test	75·3	88·5	96·3
No. 30B (Durham)	Shatter Index on receipt	87·8	95·2	97·7
	,, ,, ,, re-test	87·9	95·8	98·2
No. 44 (S. Yorks.)	Shatter Index on receipt	67·5	77·7	89·7
	,, ,, ,, re-test	70·0	80·5	91·4
No. 45A (Derby)	Shatter Index on receipt	47·0	67·8	85·7
	,, ,, ,, re-test	54·5	74·0	88·4

With the harder cokes the 1½-in. shatter index was but little affected by the fact that the coke had previously been subjected to dropping four times from a height of 6 ft. The 2-in. index may be altered considerably by such treatment, but, as illustrated by coke No. 40B (a Lancashire beehive coke), it is not necessarily raised. It will be understood that the treatment accorded to the coke during the shatter test is considerably more severe than it can be assumed to have received before it is tested at the blast furnaces. There, it is usually sampled from the wagons on receipt, having undergone, say, one drop of 6 ft.; or from bunkers, after, say, two drops of 6 ft. Actual tests of the same consignment of coke at the ovens and at the blast-furnaces (recorded in Table XL) showed that the results were, in fact, almost identical. The tests were carried out daily during a fortnight. The blast furnaces were 40 miles distant from the coke-ovens.

TABLE XL.—COMPARATIVE TESTS OF HARDNESS OF COKE AT OVENS AND AT BLAST FURNACE

	Average Shatter Indices.		
	2-in.	1½-in.	1-in.
Coke at ovens	70·5	82·1	93·2
Coke at blast furnaces . .	70·4	82·2	93·1

SAMPLING COKE FOR SHATTER TESTING

From the results of the tests so far described, it will be realised that the size of the coke sampled will not seriously influence the determination of "hardness" as given by either the 1½-in. or the 1-in. shatter index. An undue proportion of coke from the bottom of an oven in the sample would, however, give a low result. The sample should be fairly representative of all horizons in the oven.

Sampling from a Coke Car after Quenching.—Representative samples are probably best obtained when the coke is discharged from the ovens, through a quenching hood, into a coke-car. For the front end of the charge can be pushed out and a complete vertical section, over a length of, say, 2 ft., then discharged at the remote end of the car where it can be kept separate from the rest of the charge.

Sampling from an Inclined Bench.—When the coke is pushed through a quenching hood on to an inclined bench, a representative sample can be obtained by traversing the " fan " of coke, collecting pieces from the full fan width with a fork after the portion of the charge from near the discharge-side door has been picked up.

Sampling from a Conveyor.—When central quenching is practised, the coke is most satisfactorily sampled from the conveyor after it has been loaded from the cooling wharf. Pieces should be taken at convenient intervals until about 3 to 5 cwt. have been collected.

Sampling at the Blast Furnaces. (a) *From Wagons.*—It has been found to be fairly simple to obtain a sample of coke at the blast-furnace plant, sufficient to allow of the determination of its " size analysis " on receipt as well as its hardness, when the coke has been transported in wagons having side doors. A door is dropped and, after about one-third of the contents of the wagon has been unloaded, a vertical face of coke on each side of the door remains exposed. After clearing away loose pieces, a vertical section of the coke in the wagon can be collected by touching the top coke of one of these faces with a fork, allowing it to fall forwards. The loose coke is then collected until a new vertical face becomes exposed.

Table XLI records figures for the size analyses of four wagons of coke from the same consignment sampled during one day on receipt at a blast-furnace plant.

TABLE XLI.—SIZE ANALYSES OF COKE FROM WAGONS AT BLAST-FURNACE PLANT

Wagon No.	Per cent.				
	On 4-in.	On 3-in.	On 2-in.	On 1½-in.	On 1-in.
1534	33·6	62·4	82·8	92·2	96·9
1693	19·8	44·4	79·0	90·1	95·3
4789	27·5	63·8	79·5	88·1	94·2
1886	23·1	48·2	78·2	88·9	95·1
Average	26·0	54·7	79·9	89·8	95·4

The coke sampled had been made from a mixture of two coals having different coking properties. These were not blended in

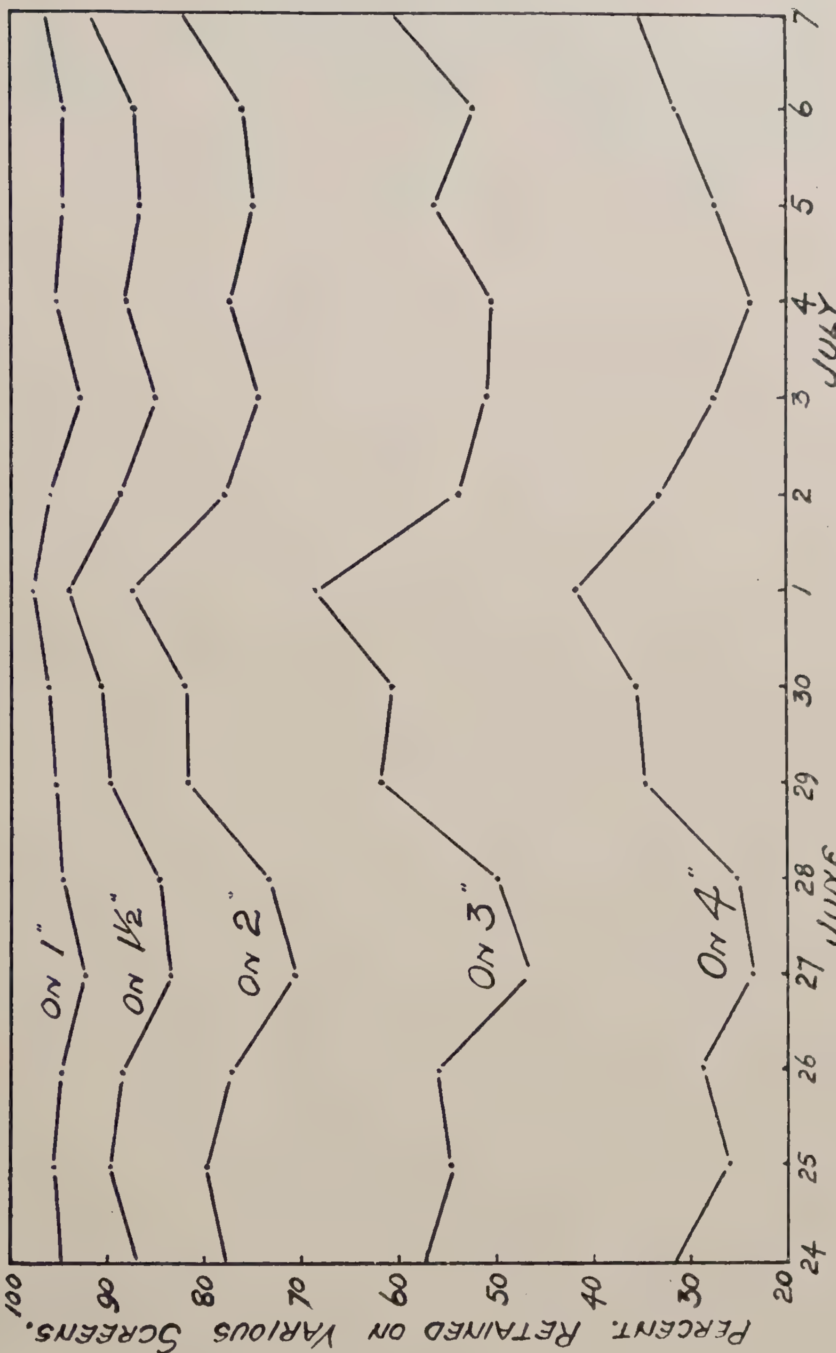


FIG. 32.—Daily Size Analyses of Coke No. 17JL on Receipt at a Blast-furnace Plant.

definite proportions, so that the quality of the coke produced at the ovens varied from day to day. Fig. 32 records average daily size analyses of this coke, sampled in the manner suggested, over a period of a fortnight. The graphs for the different sizes are of nearly the same contour, showing that the method of sampling was satisfactory.*

(b) *From Hoppers.*—When the coke is dropped from bottom or side doors into hoppers, samples can conveniently be collected as from a conveyor, *i.e.* at intervals during the discharge of the hopper.

SHATTER INDICES OF COKES

In the Appendix to this Report, the shatter indices of all the cokes we have tested are recorded. In Table XLII, typical examples, arranged in decreasing order of hardness, for cokes from different districts are given.

TABLE XLII.—SHATTER INDICES ($1\frac{1}{2}$ IN.) OF SERIES OF REPRESENTATIVE COKES

Coke No.	District.	Shatter Index ($1\frac{1}{2}$-in.).	Remarks.	
1	S. Wales	97·2	Foundry coke	Shatter index over 95·0
39	"	96·9	" "	
43	"	96·3	" "	
14	"	95·8	" "	
10	Westphalia	95·7		
11	"	95·7		
6	Durham	93·2	Foundry coke	Shatter index 95 to 90
41	"	92·9	" "	
30A	"	92·7	" "	
36B	Sarre	92·7		
8B	S. Wales	92·0		
31A	S. Yorks.	91·7	Beehive foundry coke	
23A	Durham	90·6	Foundry coke	
2	"	90·2		
40B	Lancs.	89·3	Beehive foundry coke	Shatter index 90 to 85
40A	"	88·8	" " "	
17K	S. Yorks.	88·6		
13E(I)	"	88·1		
24	Kent	87·9		
20A	Cumberland	87·7		
29B	S. Yorks.	86·7		
3A	"	86·3		
17L	"	85·2		
5	Durham	85·1		
18B	S. Yorks.	83·6	Shatter index 85 to 80	
16	Lancs.	82·8		
33	S. Yorks.	81·8		
34	"	81·7		
17G	"	81·7		
17B	"	81·6		
4	"	80·0		

---

* It follows that with any given consignment of coke complete size analyses as carried out in these tests would be unnecessary. The general character of the coke would be sufficiently well indicated by a determination of the percentage of on-$1\frac{1}{2}$-in. coke present.

TABLE XLII *continued.*

Coke No.	District.	Shatter Index ($1\frac{1}{2}$-in).	Remarks.
20B	Cumberland	79·8	Shatter index 80 to 75
17H	S. Yorks.	79·0	
29A	,,	79·0	
32	,,	78·1	
7	,,	77·1	
29H	,,	77·0	
21A	Cumberland	76·6	
26B	S. Yorks.	76·4	
36A	Sarre	75·0	Shatter index 75 to 65
21B	Cumberland	74·9	
22F	Derby	74·3	
35	S. Yorks.	74·1	
28B	Derby	72·2	
28D	,,	72·2	
28E	,,	72·0	
38A	S. Yorks	71·6	
28F	Derby	69·9	
23B	S. Yorks.	69·4	
28A	Derby	67·3	
22D	,,	66·6	
22B	,,	66·4	
15	,,	66·3	

Averages.

South Wales	96·6	S. Yorks.*	80 7
Durham	90·9	Derbyshire	69·7

* Excepting beehive foundry coke.

Cokes from South Wales, where the lowest fuel consumptions per ton of pig are recorded, head the list, with two Westphalian cokes which proved to be more economical than Durham coke, in both foundry and blast-furnace practice, during the coal stoppage of 1926. Most of the Durham cokes are near the head of the table, though one (No. 5) comes rather low down in the scale. The consumption of this coke per ton of pig was always found to be higher than that of No. 6 when interchanged with it in the same furnace. The Durham cokes No. 2 (shatter index 90·2) and No. 23A (shatter index 90·6) were each found to effect savings in fuel consumption of from 3 to 4 cwt. per ton of pig when substituted for mixtures of Yorkshire cokes having an average shatter index of 80. The Yorkshire coke No. 3A, which has the highest shatter index (86·3) of any commercial blast-furnace coke at present made in Yorkshire, has been recognised as the best of the Yorkshire cokes on trial at blast furnaces. The Derbyshire cokes appear at the lower end of the scale of hardness. They are regarded by most blast-furnace operators as inferior cokes.

The general conclusion thus presents itself that a coke with a high shatter index is superior in quality (for blast-furnace use) to one with a low index. Although other qualities, *e.g.* moisture, ash and sulphur contents, affect the value of a coke, this superiority finds expression in the average prices current, at the ovens, for blast-furnace cokes during the latter part of 1928. They were: South Wales (average shatter index 97), 20*s.*; Durham (average shatter index 91), 18*s.* 6*d.*; Yorkshire (average shatter index 81), 13*s.* 6*d.*

The shatter test can therefore be recommended to the blast-furnace operator to measure the relative hardness of cokes offered to him; and to the coke producer to determine the effect of modifications in the coking process. We have found that the hardness of cokes produced in the Midland area can be materially increased by simple means, which are described in detail in Part II of this Report.

It must be remembered that the shatter test is empirical. The results of tests cannot be comparable unless standard procedure is adopted. The standard specification of the shatter test advocated by the Midland, Northern and Scottish Coke Research Committees (see p. 95), should be closely followed and the results of tests which do not conform with this standard procedure should be neglected. In the interpretation of the average results of the tests we suggest, for the reasons already given, that most significance should attach to the 1½-in. and 1-in. indices.

APPENDIX

THE NORMAL RELATIONSHIP BETWEEN THE SHATTER INDICES

The normal relationship between the 2-in., 1½-in., 1-in. and ½-in. shatter indices of cokes is shown in Table I for cokes having 1½-in. indices (our usual standard) of between 95 and 65, by stages of 2·5.

TABLE I.—NORMAL RELATIONSHIP BETWEEN SHATTER INDICES OF COKES.

2-in.	1½-in.	1-in.	½-in.
87·5	95·0	98·0	98·9
84·0	92·5	97·0	98·5
81·0	90·0	96·0	98·3
77·5	87·5	95·0	98·0
74·0	85·0	93·5	97·8
71·0	82·5	92·5	97·7
67·5	80·0	91·5	97·6
64·0	77·5	90·0	97·4
61·0	75·0	89·0	97·3
57·5	72·5	88·0	97·2
54·0	70·0	87·0	97·2
51·0	67·5	86·5	97·1
47·0	65·0	85·5	97·0

If, for a given 1½-in. index, the 2-in. index is higher than the normal as recorded in this table, the coke is usually abnormally blocky; if the 2-in. index is lower than the normal, the coke is abnormally prismatic. If the 1-in. and ½-in. indices are lower than the normal, the coke is usually friable.

CHAPTER VIII

THE REACTIVITY OF COKE

THE property, or group of properties, of coke of interacting with oxygen and with carbon dioxide, conveniently termed its "reactivity," has formed the subject of much study and discussion. For the most part, the study of the reactivity of coke has been by laboratory experiments on a small scale and at comparatively low temperatures; whilst discussion of the results of such experiments has, unfortunately, frequently been transferred to conditions of blast-furnace operation—the high hearth temperatures, for example—which the laboratory conditions in no wise approach. It is unfortunate, also, that the trend of such discussions has often been influenced by reports from blast-furnace operators as to the behaviour of different fuels, couched in indefinite terms and leading to confusion of thought as regards the real significance of coke reactivity in blast-furnace working.

EARLY OBSERVATIONS ON THE REACTIVITY OF COKE

Reference has already been made (p. 17) to the early work of Bell (*loc. cit.*), from which he concluded that the use of a "soft" coke, markedly reactive towards carbon dioxide, would entail excessive "solution" loss in the shaft of the blast furnace, and was therefore to be avoided. This conclusion received general acceptance in this country, the "unreactive" beehive coke being at that time most highly prized as a blast-furnace fuel. In Germany, on the other hand, the most-valued fuels were wood charcoal and "meiler" coke (made from lumps of hard coal carbonised in open mounds), fuels which Thörner (*Stahl u. Eisen,* 1886, **6**, 77), using Bell's laboratory test, showed to be more reactive towards carbon dioxide than the more common coke then made from fine coal in narrow retort-ovens, with or without by-product recovery.

It may here be remarked that such comparisons of ordinary coke with special fuels of recognised blast-furnace value, such as wood charcoal, have formed the basis of most discussions regarding the significance of the relative reactivities of oven cokes in blast-furnace working. We show later that any comparison of the behaviour of oven coke, made from fine coal, with that of either wood charcoal or "meiler" coke, made from lump coal, is misleading, those two special fuels requiring special consideration. (See appendix to this chapter.)

Interest in coke reactivity perhaps reached its height during the later years of the Great War, when American blast-furnace operators called for a " fast-driving " coke to meet the demands for increased outputs of iron. The coke demanded was one which would burn at a fast rate at the tuyeres. As early as 1914, Brassert (see Johnson, " The Principles, Operation and Products of the Blast Furnace," New York, 1918, p. 171) asserted that " what the blast furnace requires is a coke which will burn rapidly and with intensity at the tuyeres, yet which has a sufficiently strong structure and hard surface to resist abrasion and solution by carbon dioxide in the upper part of the stack." Howland (*loc. cit.*), from an examination of the performance of a number of American blast furnaces smelting Mesabi ores with both beehive and by-product oven cokes, concluded that " the most desirable thing about a coke is that quality in the carbon which will allow of its being instantaneously burnt to carbon monoxide." This conclusion was based on calculations which showed that the amount of carbon gasified above the tuyeres, per ton of pig, was nearly constant despite differences in coke consumption ranging from 2,600 to less than 1,600 lb. per ton of pig.

Constancy in the amount of carbon gasified above the tuyeres by the oxygen of the ore, involving the so-called " direct reduction " of the ore, implies that in a furnace of low coke consumption the carbon taking part in direct reduction forms a higher percentage of the total carbon charged than it does in a furnace of high coke consumption. Howland argued, therefore, that the greater the proportion of the carbon used for direct reduction of the ore the greater the economy of fuel. Further, since the reactions of direct reduction are endothermic, high temperatures are necessary for their promotion. Such high temperatures would be obtained by the coke burning rapidly to carbon monoxide at the tuyeres, the direct reduction reactions taking place in a zone immediately above. If the reaction between the coke and oxygen were slow, more carbon would be necessary to produce the required temperature at the point desired than if the coke were a rapidly-burning one. It will be shown later, from our own experiments, that the temperature of the fuel-bed is dependent not only on the rate of combustion of the coke, but, under standard conditions of test, is dependent upon a specific property of the coke.

It should be pointed out that there were certain inaccuracies in Howland's calculations, for he made no allowance either for nitrogen in the coke or for moisture in the air. Hollings (*Journ. Iron and Steel Inst.*, 1926, **113,** 285) has shown that these omissions may seriously influence calculation of the extent to which " direct reduction " of the ore takes place. For example, on assuming, with Howland, the use of dry air at 62° F., and ignoring the nitrogen in the coke, calculation for one furnace showed that 201·5 lb. of carbon were consumed by direct reduction of the ore, 1,182·5 lb. being burnt at the tuyeres. If, however, the air were assumed to be at 90·5° F. and to contain 7·5 grams of moisture per cu. ft. (as it does during summer in America), and if the nitrogen content of the coke were assumed to be 1 per cent of its fixed carbon, the calculations for the same furnace showed 1257·8 lb. of carbon burnt at the tuyeres, leaving only 126·2 lb. consumed by direct reduction of the ore. It would appear, therefore, that Howland's estimate of the importance of "direct reduction" in blast-furnace economy may have been considerably exaggerated. Clements (" Blast Furnace Practice," Vol. I, p. 176. London, 1929) asserts that the differences in the fuel consumptions in the furnaces studied by Howland were due, not to differences in the amounts of indirect and direct reduction, but to wide variations in the hearth heat requirements. This is demonstrated by the relationship between the amounts of limestone and fuel charged per ton of pig (see Fig. 33), for the limestone, being an approximate expression of the slag volume, is also a rough measure of the hearth heat requirements.

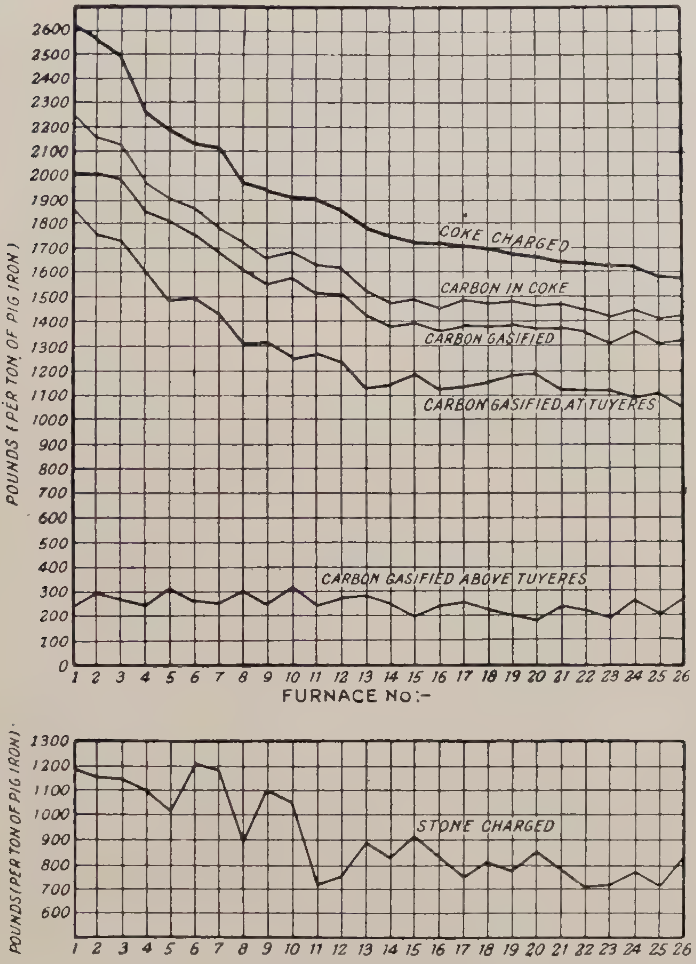


FIG. 33.—Howland's Series of Blast-furnace Results.

Koppers (*Stahl u. Eisen*, 1921, **41**, 1173, 1254), from a study of the results of Howland and others, came to the conclusion that the cause of variation in coke consumption in different blast-furnaces was differences in " combustibility " of the cokes, as measured by the time taken for them to be converted into carbon monoxide. Koppers does not give his train of reasoning, but he appears to have been influenced considerably by the results obtained in charcoal blast furnaces, quoting two where the CO_2/CO ratio of the top gases was as high as with the furnaces having the lowest fuel consumption in Howland's series. In this connexion, he quotes observations by Wüst that the consumption of fuel per ton of pig is, as a general rule, about 150 kg. (330 lb.) less with charcoal than with coke, despite the lower air-blast temperature. According to Wüst (Koppers, *loc. cit.*, p. 1177) the oxidising zone in front of the tuyeres is less with charcoal than with other fuels, so that there is less possibility of re-oxidation of reduced iron with consequent further fuel requirements for re-reduction.

MEASUREMENTS OF THE REACTIVITY OF COKE

Howland's and Koppers' deduction that ready combustibility is a desirable quality of a coke has aroused considerable interest in the subject, particularly in Germany, and has led to numerous attempts to obtain a measure of the " combustibility " or " reactivity " of coke. A comprehensive summary of the many methods suggested is given by Agde and Schmitt (" Theorie des Reduktionsfähigkeit von Steinkohlenkoks," Halle (Saale), 1929).

Probably the most satisfactory way of determining the significance of coke reactivity in blast-furnace working is a full-scale blast-furnace trial, despite the multitude of factors involved. This method has been successfully employed by the United States Bureau of Mines, by tests at works and at an experimental furnace. For example, Perrott and Sherman (*Proc. Eng. Soc. W. Penn.*, 1924, **39**, 351) have reported the result of a study of analyses of gases drawn from the hearths of thirteen blast furnaces using different fuels, ranging from wood charcoal to beehive coke. It was evident that the removal of oxygen from the blast took place in a narrow zone, from 24 to 30 in. in diameter, around each tuyere, and that the carbon dioxide produced disappeared within 32 to 40 in. The oxidation zones for the different furnaces did not vary much, and such small differences as were found bore no apparent relationship to the amount of coke used per ton of pig or to its properties.

With regard to small-scale laboratory methods of studying the reactivity of coke, such as have been so widely used in Germany, it will be agreed that in one and all of them the conditions of test depart so widely from those of blast-furnace practice that only by the correlation of the results obtained in them with those of large-scale trials can they hope to become of practical value. For example, laboratory tests are usually carried out at temperatures less than 1000° C., as compared with the 1500–2000° C. of the furnace hearth.

Of the few investigators who have seriously considered the effect of the high hearth temperatures on the relative reactivities of different cokes, Arend and Wagner (*Rev. de Met.*, 1924, **21**, 585; *Fuel*, 1926, **5**, 106) are responsible for the diagram reproduced in Fig. 34. This shows: (1) Boudouard's well-known equilibrium diagram between CO_2, CO and C at different temperatures. For equilibrium to be attained with different forms of carbon, a time of contact of many hours may be required at temperatures below 500° C., but similar curves to Boudouard's may be obtained by passing carbon dioxide over the carbon at a known rate and measuring the amount of reduction. Curves (2) to (5) were obtained in that way, (2) for wood charcoal, (3) for by-product oven coke, (4) for an American beehive coke and (5) for retort carbon. At 1000° C., the reactivities of these four materials, expressed as percentages of the carbon dioxide reduced by them, are: Wood charcoal 97; by-product coke, 80; beehive coke, 43; retort carbon, 26. At 1100° C., the reactivity of wood charcoal becomes approximately 100, as does that of retort carbon at 1600° C. At the temperatures near the tuyeres of a blast furnace (about 2000° C.), it is clear that

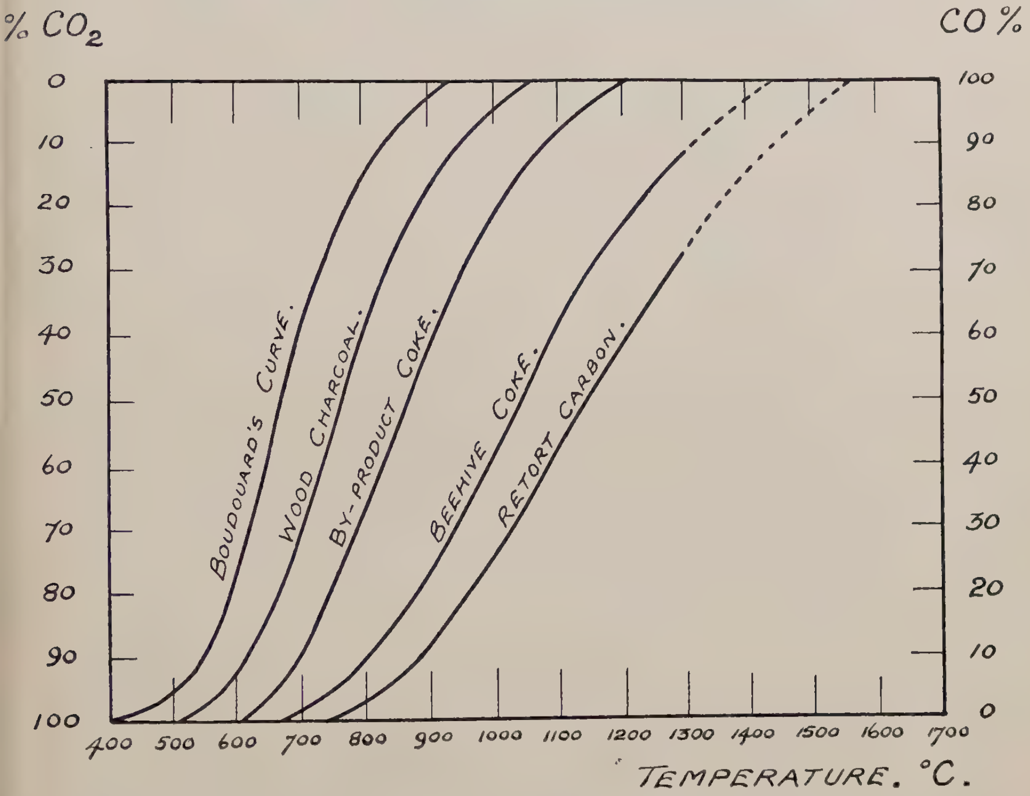


FIG. 34.—Arend and Wagner's Diagram of Variation of Reactivity with Temperature.

any differences between the reactivities of different cokes would be so small as to be negligible.

Of intermediate-scale tests, in which coke pieces of fairly large size are burnt in a deep fuel-bed, the "Salamander" is perhaps the best known. In this test the weight of coke burnt in a given time in a vertical pot under natural draught is measured. It suffers from the disadvantage that the air supply is not constant.

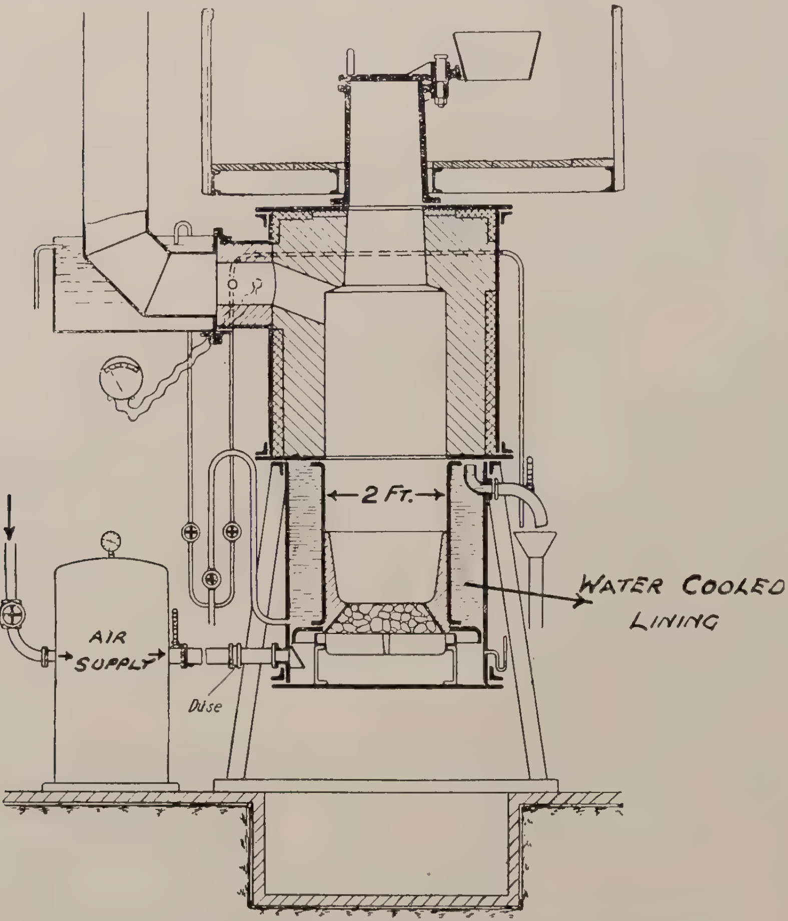


FIG. 35.—Diagram of Combustibility of Furnace used by Haüsser.

The most comprehensive series of tests in which a deep fuel-bed was used is that recorded by Haüsser and Bestehorn ("Untersuchungen über die Verbrennlichkeit von Hüttenkoks in Technischen Kornungen," Halle (Saale), 1926). A furnace 2 ft. in diameter, its lower half water-jacketed, was used (see Fig. 35), with a constant air-blast of about 9,500 cu. ft. per hour, enabling coke to be burnt at a rate of about 67 lb. per sq. ft. of hearth area per hour. Each trial was continued during 6 hours, and analyses of the top gases were made at intervals. The " combustibility " of the coke could be expressed in terms of the carbon monoxide formed. Over 100 cokes, of which analytical and manufacturing details are given, were tested in this way. Haüsser and Bestehorn found but small differences in the combustibility of cokes dependent on the kind of coal from which they were made, and no material differences dependent on the alterations in the method of manufacture, such as coking time and oven width. Considerable differences in combustibility were, however, noticed dependent on the size of the coke pieces used for the test, thus :

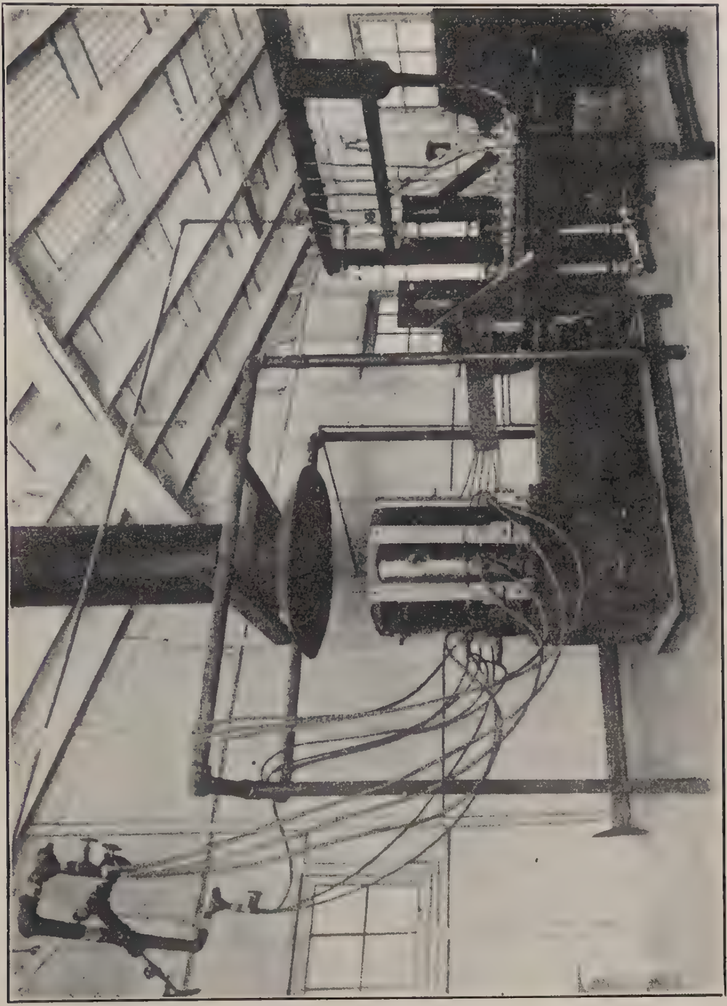


Fig. 36.—View of Combustibility Furnace used by Kreisinger.

Size of Coke Pieces.	"Combustibility." (Carbon monoxide, per cent. of theoretical.)
$1\frac{3}{16}$ to $2\frac{3}{8}$ in.	89·4
2 to $2\frac{3}{4}$ in.	72·4
$2\frac{3}{4}$ to $3\frac{1}{2}$ in.	68·1

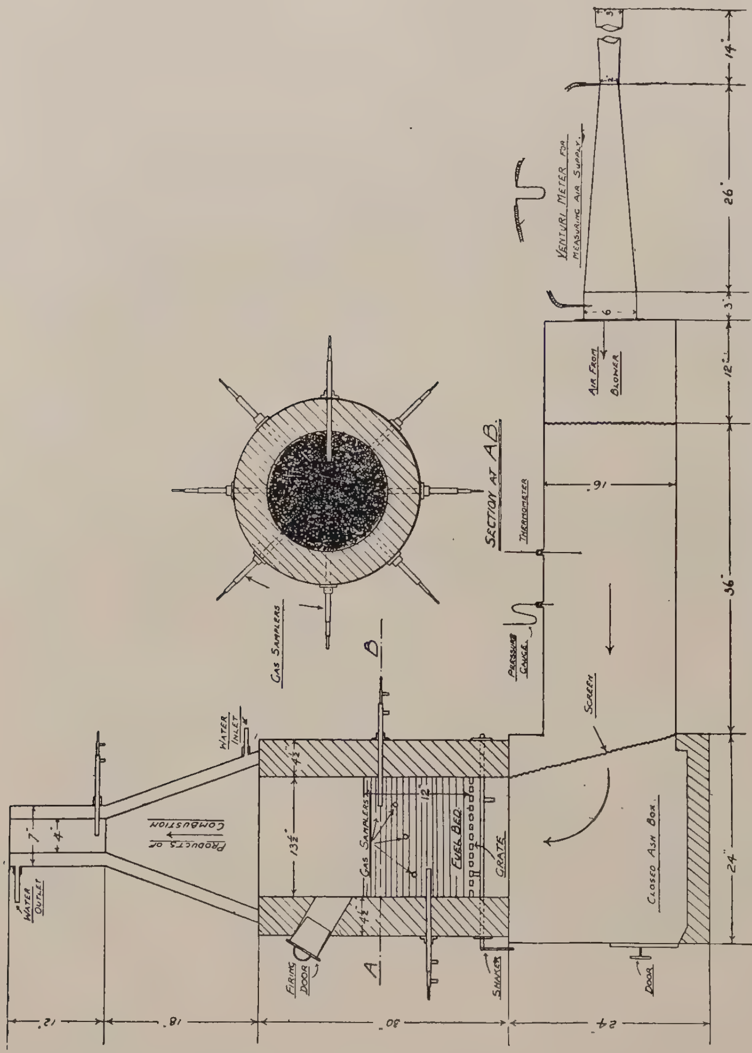

Venturi Meter for measuring air supply
Air from Blower
Section at AB
Thermometer
Pressure Gauge
Screen
Gas Samplers
Water Inlet
Water Outlet
Products of Combustion
Gas Samplers
Fuel Bed
Grate
Closed Ash Box
Firing Door
Shaker
Door
A
B
14"
26"
3"
6
12"
16"
36"
24"
12"
13½"
4½"
4½"
7"
4"
12"
18"
30"
24"

FIG. 37.—Diagram of Combustibility Furnace used by the Midland Coke Research Committee.

Haüsser and Bestehorn noted that many good blast-furnace cokes were of low "combustibility," so that their value as blast-furnace fuels presumably depended on some other property, on their size, for example, on their impact and abrasion hardness. From "shatter" and "tumbler" tests made by them, they concluded that the hardness of the cokes, rather than their combustibility (as Koppers believed), was affected by the width of the oven used in their manufacture and by the coking time.

The United States Bureau of Mines have used a furnace, of 1 sq. ft. grate area, for testing cokes. The furnace (see Fig. 36) was originally described by Kreisinger, Ovitz and Augustine (U.S. Bureau of Mines Tech. Paper No. 137, 1916), who burnt coke, anthracite and bituminous coal in it, with 6-in. and 12-in beds, at rates varying from 20 to 185 lb. per hour. Gas samples were withdrawn at 1½-in. intervals above the grate-level through water-cooled tubes. The composition of the gases in the fuel-bed was but little affected by the rate of combustion of the fuels, which was entirely dependent on the rate of supply of air. In 1923, Sherman and Blizard (*Trans. Amer. Inst. Min. Eng.*, 1923, **69**, 526) recorded the results of tests of four cokes made in the same furnace with a water-cooled hood attached to enable an average sample of the gases above the fuel-bed to be taken. In these tests, the rate of combustion appeared to have little effect on the composition of the final products, whilst the "combustibility" of the four cokes (calculated from the ratio $\frac{CO_2 + CO}{2CO_2 + CO + 2O_2} \cdot 100$) differed by but 4 per cent. Later, Sherman (*Iron Age,* April 9, 1925) made com-

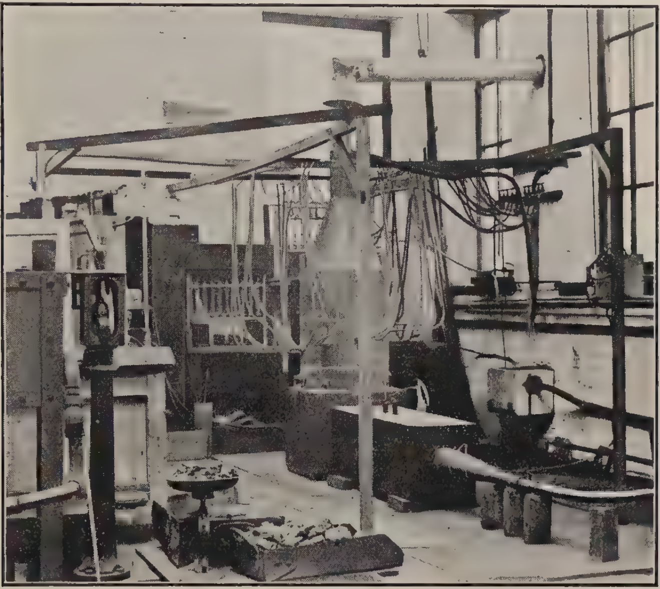


FIG. 38.—General View of Furnace used by the Midland Coke Research Committee.

parative tests of three beehive, one by-product coke and a wood charcoal. The "combustibilities," calculated from the stack gases, were 69, 72 and 73 for the beehive cokes, 67 for the by-product coke (a sample from the oven wall) and 95 for the wood charcoal.

THE MIDLAND COKE RESEARCH COMMITTEE'S METHOD OF TEST

Our own experiments have been made with the same type of furnace as that used by the Bureau of Mines investigators. A diagram of the furnace is reproduced in Fig. 37 and two photographs of it in Figs. 38 and 39. The lining is of sillimanite except for 2 in. above the grate, where a hard firebrick is used the better to resist the abrasive action of the coke when the grate is rocked during a test. The internal diameter of the furnace is 13½-in., and the grate area 1 sq. ft. The grate is in two halves, and can be rocked by a rod with cams attached which passes underneath to the outside of the furnace casing. The furnace casing and the wind box are of mild steel plates caulked with iron cement. At 1½-in. intervals above the grate, stepped at each 45° on the circumference of the furnace, short metal sleeves pass through the casing and lining. Through these sleeves water-cooled gas-sampling pipes of copper can be introduced into the fuel-bed. As illustrated in Fig. 40, each sampling-pipe consists of three concentric tubes so arranged that a water stream can enter through the inner annulus and pass to waste through the outer one. The gases are withdrawn through the centre tube and collected over mercury in samplers of special design (see Figs. 41 and 42).

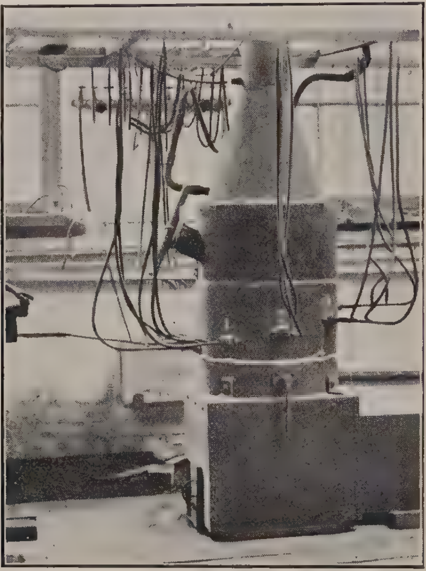
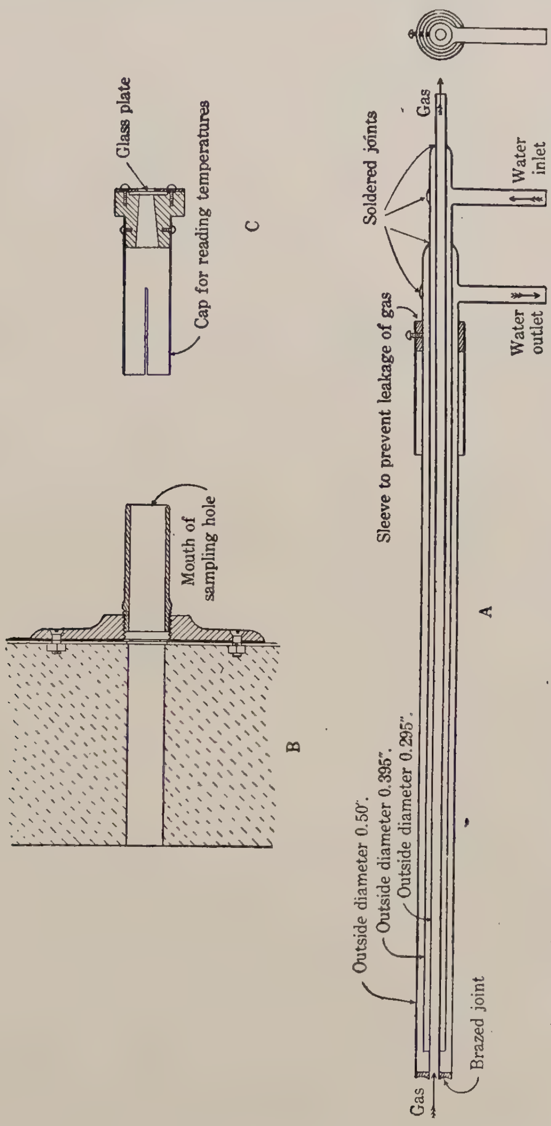


FIG. 39.—View of Furnace showing Charging Door.

To carry out a test, about 8 lb. of graded 1- to $1\frac{1}{2}$-in. coke are charged on to the grate and ignited under natural draught by a large bunsen flame, the ash-pit door being open. So soon as the coke is well alight, the ash-pit door is closed and sealed and the air-blast turned on to the required amount as measured by a Venturi meter. The depth of the fuel-bed is now increased to 12 in. and its temperature observed at frequent intervals until it appears to be steady. Measurements of temperature are made, with an optical pyrometer


Glass plate
Cap for reading temperatures
C
Mouth of sampling hole
B
Soldered joints
Gas
Sleeve to prevent leakage of gas
Water inlet
Water outlet
A
Outside diameter 0.50".
Outside diameter 0.395".
Outside diameter 0.295".
Brazed joint
Gas

A water-cooled gas sampler. B, ~~Mouth of~~ sampling hole; C, cap placed over the mouth of the sampling hole when the temperature in the fuel bed was read.

FIG. 40.—Water-cooled Copper Sampling Pipe and other Furnace Details.

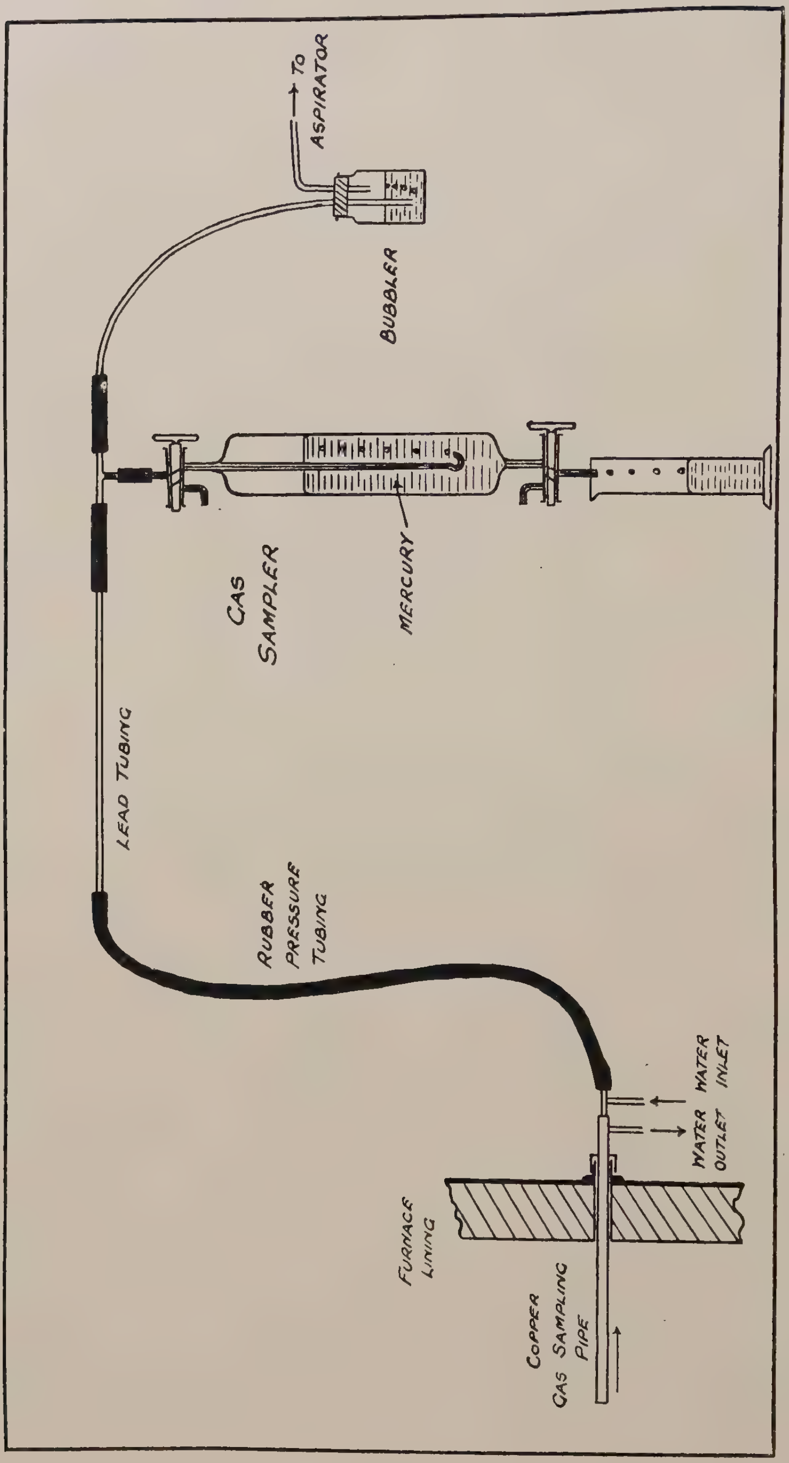

TO ASPIRATOR
BUBBLER
GAS SAMPLER
MERCURY
LEAD TUBING
RUBBER PRESSURE TUBING
WATER INLET
WATER OUTLET
FURNACE LINING
COPPER GAS SAMPLING PIPE

FIG. 41.—Gas Sampler and Diagrammatic Scheme of Sampling (not to scale).

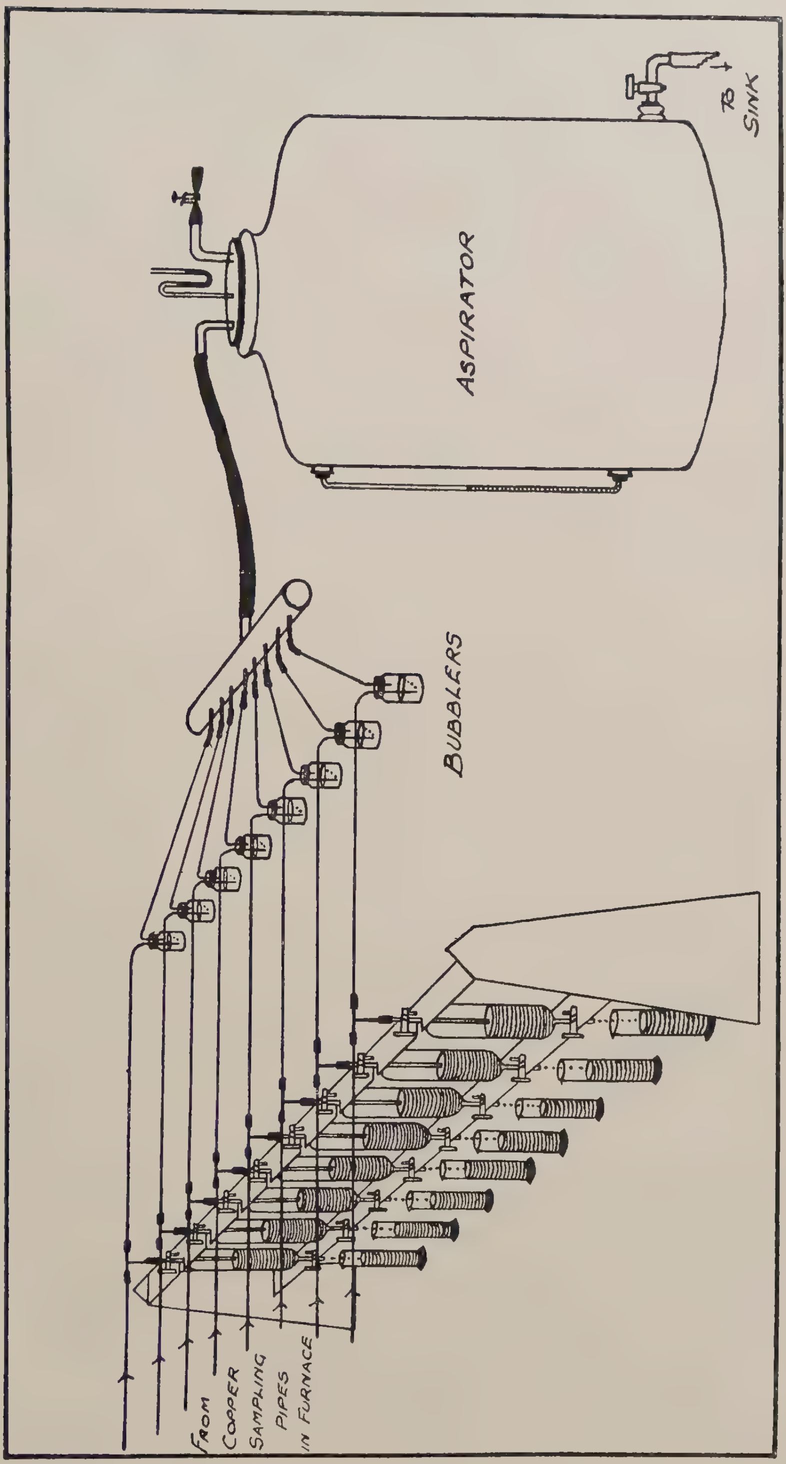

ASPIRATOR
TO SINK
BUBBLERS
FROM COPPER SAMPLING PIPES IN FURNACE

FIG. 42.—Diagrammatic Representation of Simultaneous Sampling of Gases from Different Levels in Fuel-bed.

of the disappearing filament type, through an observation tube with a glass window which can be attached at one or other of the sleeves through which the gas-sampling pipes are passed. When the temperature of the fuel-bed is steady, its height is increased to 14 in. The gas-sampling pipes are then inserted and gases drawn through them during five minutes (by means of an aspirator) to sweep out air, after which the streams are diverted into the samplers. Samples of the gases at 1½-in intervals above the grate are thus collected simultaneously during a period of three minutes. The sampling over, the pipes are withdrawn and, after a short interval to allow the disturbance caused by their withdrawal to be rectified, temperature measurements are again made. This cycle of operations is repeated after the addition of more coke to restore the height of the fuel-bed to 14 in. The air-blast is then stopped and the furnace-top sealed with a steel plate. When the furnace is cool, it is emptied and the amount and size of clinker are determined. The gas-samples are analysed for carbon dioxide, carbon monoxide and oxygen, a modified form of Hempel apparatus being used (see *Fuel*, 1922, **1**, 26).

A typical record of a test, which serves to outline the procedure, is given in Table XLIII.

TABLE XLIII.—TYPICAL RECORD OF "COMBUSTIBILITY" TEST.

Coke No. 13B(b) (S. Yorks.). June 13, 1928.

Time (a.m.).	
9.20	Burner on, 16 lb. of coke fed.
10.15	12 lb. of coke fed, 12-in. coke-bed.
10.16	Blast on.
10.19	Coke-bed burnt through red at 12-in. level.
10.29 to 10.31	12 lb. of coke fed, 13-in. bed.
10.50 to 10.51	12 lb. of coke fed, 13-in. bed.
10.58 to 11.10	First set of temperature readings taken.
11.11 to 11.13	16 lb. of coke fed, 14-in. bed.
11.18	Aspirator started for gas samples.
11.21 to 11.24	First set of gas-samples taken.
11.25 to 11.26	8 lb. of coke fed, 13½-in. bed.
11.27	Aspirator re-started.
11.30 to 11.33	Second set of gas samples taken.
11.34 to 11.41	Second set of temperature readings taken.
11.42	12 lb. of coke fed, 12-in. bed. Blast off.

Temperature, Pressure and Humidity of Air-blast.

Time (a.m.).	Blast Temp. (° C.).	Blast Press. (in. w.g.).	Dry Bulb (° F.).	Wet Bulb (° F.).
10.45	22·0	0·7	61·0	57·0
10.55	23·4	0·8	61·5	56·5
11.6	24·2	0·8	62·0	57·5
11.15	25·4	1·0	62·5	57·5
11.25	24·9	0·95	63·5	58·0
11.35	25·3	1·0	64·0	58·5

Coke Bed Temperatures.

Observation Hole No.	First Series.	Second Series.
1	1600	1600
2	1650	1680
3	1600	1620
4	1550	1510
5	1200	1480
6	1150	1300
7	1125	1150
8	1040	1080

Gas Analyses. Per Cent.

Sampling Point No.	CO_2.		CO.		O_2.	
	1st set.	2nd set.	1st set.	2nd set.	1st set.	2nd set.
1	0·3	2·8	0·2	0·3	19·7	16·9
2	14·8	16·1	0·5	0·8	5·1	3·4
3	15·8	17·3	5·1	2·0	1·1	1·6
4	9·5	13·3	16·6	10·7	Nil	0·6
5	12·0	13·4	11·4	10·2	1·0	0·8
6	8·7	7·2	18·3	21·2	0·5	Nil
7	6·0	5·1	22·6	22·9	0·6	1·0
8	7·2	5·4	21·7	23·7	Nil	0·6

Height of fuel-bed at which oxygen disappeared (inches)	4 (1st set)	4 (2nd set)
Height of fuel-bed at which CO reached 20 per cent. (inches)	10 (1st set)	9 (2nd set)
Maximum temperature (° C.)	1650 (1st set)	1680 (2nd set)
Average temperature (points 1 to 7) (° C.) .		1455

Our procedure differs in several respects from that of the Bureau of Mines investigators, to whom this form of test is due. For example, we do not maintain a constant depth of fuel-bed, as did Kreisinger, Sherman and Blizard, for the reason that, with low rates of coke consumption, over-frequent feeding of coke to the bed disturbs its temperature. Our method of building up a bed of about 14 in. thickness and allowing it to burn down to about 12 in. before recharging provides a period of constant-temperature conditions of between 8 and 9 minutes, during which the gas samples are collected and the temperature measurements made.

Again, whereas the American investigators made their temperature measurements at each sampling hole, one by one, immediately after the withdrawal of each water-cooled sampling pipe, we have found it preferable to remove all the sampling pipes from the fuel-bed simultaneously and, after a short interval to allow a steady temperature to be attained, to make the series of temperature measurements as rapidly as possible. The ends of our sampling pipes are midway between the axis and the wall of the furnace.

Sherman and Blizard's (*loc. cit.*) method of expressing the combustibility of the cokes by means of the expression

$$\frac{2CO_2 + 2O_2 + CO}{CO_2 + CO} \cdot 100$$

(which gives the amount of gaseous carbon per cent. of the theoretical), as determined from the stack gases, has not proved entirely satisfactory, because of the difficulty of ensuring that no air enters at the seal between the water-cooled hood and the furnace lining, or at the charging door. Air might also pass along the wall of the furnace in variable quantity, according to the condition of the lining and the manner of settlement of the coke charge. There is evidence in the graphs recording the results of our tests (as also in Sherman and Blizard's) of a lower carbon monoxide content of the gases at the top of the fuel-bed than at the 10½-in. level, whilst the stack gases almost invariably contain less carbon monoxide than do those at the top of the bed. We have therefore abandoned the analysis of the stack gases, and prefer to express the "reactivity with oxygen" of the coke by the distance above the grate at which oxygen no longer appears in any quantity in the gas sample, and the "reactivity with carbon dioxide" by the distance at which the gases contain 20 per cent. or more of carbon monoxide.

We have tested between eighty and ninety different cokes under the same experimental conditions, namely, with a constant rate of supply of air (referred to in this Report as Rate No. 3), a standard size of coke (1- to 1½-in.) and a 12 to 14-in. fuel-bed. Other series of tests have determined the effect of using different sizes of coke with the same rate of supply of air, and the effect of varying the air supply with the same size of coke.

THE COMBUSTION OF A STANDARD SIZE OF COKE WITH A STANDARD RATE OF SUPPLY OF AIR

Reactivity with Oxygen. The outstanding observation from the tests with a standard size (1- to 1½-in.) of coke and a standard rate of supply of air is that, with all but two of the cokes tested, almost all the oxygen of the air is used within 6 in. of the grate, the rate of combustion of the coke being about 40 lb. per sq. ft. of grate area per hour. Table XLIV records, for eighty cokes, the distances above the grate at which oxygen disappeared. These distances are computed from graphs of the oxygen content of the gases at different levels of the fuel-bed. The results obtained from each second set of gas samples (see the description of the experimental method) are listed first, and considered preferably, because these samples were obtained after the initial bed of coke had been consumed. Coke at the bottom of the bed had therefore been subjected to gasification at all levels and corresponded in this respect to coke burnt finally at the tuyeres of a blast furnace.

The cokes are arranged roughly in order of their reactivity with oxygen. Wood charcoal is highly reactive, but cokes made from lumps of "hards" (having a structure similar to that of "meiler" cokes, to which reference has previously been made), and from a blend of a coking coal with anthracite duff, are equally so. But little less reactive are two cokes made from a coking coal blended with low-

TABLE XLIV.—DISTANCE FROM GRATE FOR OXYGEN DISAPPEARANCE (RATE 3).

Coke No.	Origin.	Distance for Oxygen Disappearance (in.).		Per cent. Total Porosity.	Remarks.
		2nd set.	1st set.		
53		3	3	61·8	Wood charcoal.
27B	S. Yorks.	3	3	37·9	Made from lumps of Barnsley hards (mainly durain).
29O	S. Yorks.	3	3	39·0	Blended with 30 per cent. anthracite.
22G	Derby.	3	4	50·6	Blended with 20 per cent. low-temperature coke.
25A	S. Wales.	3	5	40·0	Blended with 67 per cent. anthracite.
4	S. Yorks.	3	5	46·3	Blended with poorly-caking coal.
17D	S. Yorks.	3	6	48·6	Made from ground Barnsley hards.
17G	S. Yorks.	4	3	56·2	
29A	S. Yorks.	4	3	45·4	
38A.s	S. Yorks.	4	3	55·6	Made from washed slurry from poorly-caking coal.
25B	S. Wales.	4	3	35·9	Blended with 33 per cent. anthracite and 33 per cent. steam coal.
13B (b)	S. Yorks.	4	4	43·2	Blended with 20 per cent. ground hards.
17F	S. Yorks.	4	4	50·2	Made from ground Swallow Wood hards.
17H	S. Yorks.	4	4	57·2	
17I	S. Yorks.	4	4	56·1	
29D	S. Yorks.	4	4	52·7	Poorly-caking coal (Wath Wood and Swallow Wood).
3E (II)	S. Yorks.	4	4	51·5	Made from ½ to ⅜ in. coal.
3G (I)	S. Yorks.	4	4	46·3	Poorly-caking coal (Barnsley, Wath Wood, High Hazel).
29M	S. Yorks.	4	4	43·7	Blended with 30 per cent. anthracite.
22F	Derby.	4	4	52·7	Poorly-caking coal (Deep Soft, etc.).
17M	S. Yorks.	4	4	14·7	Retort carbon from oven walls.
51B	Leicester.	4	4	53·2	Non-coking coal briquetted with pitch.
1	S. Wales.	4	4	51·3	Blended with steam coal.
18F	S. Yorks.	4	4	55·6	
26B	S. Yorks.	4	4	52·1	Blend containing poorly-caking coals (Haigh Moor, Lidgett, Barnsley, Kent Thick).
3F (II)	S. Yorks.	4	4	56·8	
29E	S. Yorks.	4	4	54·4	Poorly caking coal (Wath Wood, Swallow Wood).
17B	S. Yorks.	4	5	45·8	
3A	S. Yorks.	4	5	51·5	Blended with 28 per cent. poorly-caking coal.
29K	S. Yorks.	4	5	46·2	Blended with 20 per cent. low-temperature coke.
52		5	4	28·4	Artificial graphite (from electrodes).
3E (I)	S. Yorks.	5	4	51·5	Made from 1 to ½ in. coal.
29C	S. Yorks.	5	4	55·0	
40A	Lancs.	5	4	44·6	
37	S. Yorks.	5	4	48·6	Made from poorly-caking coal (Barnsley).
29G	S. Yorks.	5	4	54·6	Blended with 20 per cent. poorly-caking coal (29D).
18J	S. Yorks.	5	4	50·5	Blended with 32 per cent. poorly-caking coal (Barnsley).
31A	S. Yorks.	5	4	53·8	
18C	S. Yorks.	4	6	50·3	
20B	Cumb.	4	6	50·8	
23A	Durham.	4	6	48·4	
17E	S. Yorks.	4	6	58·0	Made from poorly-caking coal (Swallow Wood).
29B	S. Yorks.	4	6	54·2	
29J	S. Yorks.	4	6	56·9	Blended with 20 per cent. low-temperature coke.
17C	S. Yorks.	5	5	46·6	Made from ground hards (Parkgate).
3E (VI)	S. Yorks.	5	5	55·2	
3E (VIII)	S. Yorks.	5	5	47·4	
43	S. Wales.	5	5	52·0	Blended with steam coal.
5	Durham.	5	5	41·0	
18E	S. Yorks.	5	5	54·4	
22B	Derby.	5	5	48·0	Blend of poorly-caking coals (Deep Soft and Barnsley).
21A	Cumb.	5	6	51·8	
19B	S. Yorks.	5	6	54·0	
3B	S. Yorks.	5	6	52·3	
3F (I)	S. Yorks.	5	6	54·6	
3C	S. Yorks.	5	7	59·2	
17K	S. Yorks.	6	3	46·8	
2	Durham.	6	4	53·8	
3E (V)	S. Yorks.	6	4	58·2	
14	S. Wales.	6	4	50·8	Blended with steam coal.
17A	S. Yorks.	6	4	51·5	
18A	S. Yorks.	6	4	58·9	
20A	Cumb.	6	4	55·6	
28B	Derby.	6	4	51·3	Poorly-caking coal (Tupton).
6	Durham.	6	5	53·7	
15	Derby.	6	5	48·0	Blended with poorly-caking coal (Tupton, Deep Hard).
8A, B	S. Wales.	6	5	41·5	Blended with 14 per cent. anthracite.
29F	S. Yorks	6	6	54·2	Blended with 20 per cent. poorly-caking coal (No. 29D).
28D	Derby.	6	6	46·4	Poorly-caking coal (Deep Soft).
28E	Derby.	6	6	48·3	Poorly-caking coal (Waterloo).
30A	Durham.	6	6	49·3	
30B	Durham.	6	6	56·0	
39	S. Wales.	6	6	57·5	
16	Lancs.	6	6	53·1	
18B	S. Yorks.	6	6	51·3	
3D	S. Yorks.	6	6	56·2	
21B	Cumb.	6	6	51·0	
22D	Derby.	6	6	49·7	Poorly-caking coal (Deep Soft).
28A	Derby.	6	6	49·7	
28C	Derby.	7	7	47·0	Poorly-caking coal (Deep Hard).

temperature coke breeze (No. 22G) and with anthracite (No. 25A), and one made from ground "hards."

If the cokes are divided into two groups according as the oxygen disappeared, on the average of both sets of gas analyses, in less than 4½ in. (the first thirty-eight on the list) or persisted beyond 4½ in. (the remaining forty-two), it appears that the more reactive group includes twenty-six made from non-caking (or poorly-caking) coals or blends of a good caking coal with a non-caking material or a material of low caking-power. Two of the cokes in the more reactive group were made from large lumps of (good caking) coal and ten from what are commonly believed to be strongly caking coals. In the less reactive group the majority of the cokes were made from strongly caking coals. Two only were made from blends with non-caking materials: No. 29J (containing 20 per cent. of low-temperature coke breeze) and No. 8A, B (containing 14 per cent. of anthracite duff). Fourteen were made from poorly-caking coals or from blends containing poorly-caking coals, seven of these being from Derbyshire coals.

The general inference is that cokes of high reactivity with oxygen in the blast furnace can be produced by blending a non-caking or poorly-caking material with a strongly-caking coal, whilst cokes made from strongly-caking coals alone are, in general, less reactive.

The coke produced from a coal of low caking power often has a low percentage total pore space, the low plasticity of the coal offering small resistance to the escape of gases. Of the cokes listed in Table XLIV that were made from charges containing poorly-caking material (forty in number), twenty-one have a total porosity of less than 50 per cent., whereas only nine of the remaining thirty-nine cokes, made from strongly-caking coals, are of such low porosity. Since the cokes made from blends containing non-caking material are amongst the most reactive with oxygen, porosity is not a dominant factor as regards reactivity; but it may be a contributory factor, for of the twelve cokes made from strongly-caking coals that appear in the more reactive group of Table XLIV, six have a total porosity of 55 per cent. (a high figure) or more.

Reactivity with Carbon Dioxide. A fuel-bed 12 in. deep, of 1- to 1½-in. coke, is insufficient to reduce to carbon monoxide all the carbon dioxide formed in the lower part of the bed. A satisfactory measure of the rate of reaction between the coke and carbon dioxide can, however, be obtained from the distance above the grate at which an arbitrary quantity of carbon monoxide—say 20 per cent.—appears in the gas-samples. With only a few of the cokes tested was less than 20 per cent. of carbon monoxide produced at a distance of 12 in. from the grate. On the other hand, 25 per cent. was rarely exceeded.

We have also found it of value to record the percentage of carbon monoxide in the gases withdrawn 4 in. above the grate, for a reason which will appear later.

Such records are given in Table XLV. As when considering the reactivity of the cokes with oxygen, more reliance is placed on the analyses of the "second set" of gas samples, which are therefore stated first. It will be seen that, in general, the reactivity of a coke with carbon dioxide (as measured by the distance above the grate at which 20 per cent. of carbon monoxide is formed) is greater according to the second set of analyses than according to the first. The reason for this is that the routine of the test usually resulted in there being less freshly-charged coke on the bed, the top of which was therefore at a higher temperature, at the time the second set of samples was taken.

Considering the same two groups of cokes as when discussing their reactivity with oxygen, it appears that, in general, the cokes that are the more reactive with oxygen are also the more reactive with carbon dioxide. The exceptions are of interest. Taking first the more reactive group (the first thirty-eight cokes in Table XLV), those for which a height of bed of more than 10 in. (average of both sets of analyses) was required for the production of 20 per cent. of carbon monoxide are:

Coke No.	Height of Bed for 20 per cent. CO (in.).		Remarks.
	2nd set.	1st set.	
29O	11	10	Blend with 30 per cent. anthracite.
17G	>12	>12	
29A	12	11	
17F	11	11	
17H	12	11	
1	12	12	Blend with steam coal.
3E (II)	11	12	
26B	12	10	Blend with poorly-caking coal.
3A	12	9	Blend with poorly-caking coal.
17M	9	>12	Retort carbon.
52	9	>12	Artificial graphite.
3E (I)	12	11	
29C	11	11	

These thirteen "cokes" that are less reactive with carbon dioxide than would be expected from their reactivity with oxygen include retort carbon and artificial graphite. These are only placed in the less reactive group from the first set of analyses. It is probable that insufficient time of burning was allowed for these dense materials, 56 lb. of which were required to build a 12-in. bed as compared with 32 lb. for most of the cokes. Seven of the thirteen are cokes made from strongly-caking coals, of which the more reactive group in Table XLV only contains ten examples. This group of thirty-eight cokes that is the more reactive with oxygen thus contains twenty-six made from blends containing non-caking or poorly-caking material and, of these twenty-six, twenty conform with the arbitrary standard of reactivity with carbon dioxide.

The exceptional cokes in the less reactive group (the last forty-two in Table XLV) are:

TABLE XLV.—REACTIVITY OF COKES WITH OXYGEN AND CARBON DIOXIDE.

Coke No.	Origin.	Distance from Grate for Oxygen Disappearance (in.).		Distance from Grate for Gas to contain 20 per cent. of Carbon Monoxide (in.).		Carbon Monoxide per cent. at 4 in. from Grate.	
		2nd set.	1st set.	2nd set.	1st set.	2nd set.	1st set.
53	(Charcoal)	3	3	5	5	13·0	17·0
27B	S. Yorks.	3	3	9	9	2·5	9·0
29O	S. Yorks.	3	3	11	10	7·5	3·5
22G	Derby.	3	4	9	8	12·5	4·5
25A	S. Wales.	3	5	7	7	8·5	5·5
4	S. Yorks.	3	5	7	8	5·5	1·0
17D	S. Yorks.	3	6	11	9	3·0	0·5
17G	S. Yorks.	4	3	>12	>12	4·5	1·0
29A	S. Yorks.	4	3	12	11	3·5	4·5
38A.s	S. Yorks.	4	3	7	8	6·0	10·5
25B	S. Wales.	4	3	9	9	3·0	18·5
13B (b)	S. Yorks.	4	4	9	10	2·0	5·0
17F	S. Yorks.	4	4	11	11	2·5	2·0
17H	S. Yorks.	4	4	12	11	6·5	4·5
17I	S. Yorks.	4	4	6	8	21·5 *	11·5 *
29D	S. Yorks.	4	4	9	9	7·0	7·5
3E (II)	S. Yorks.	4	4	11	12	—	6·0
3G (I)	S. Yorks.	4	4	9	10	5·5	4·0
29M	S. Yorks.	4	4	11	9	6·0	19·0
22F	Derby.	4	4	11	9	8·0	4·5
17M	(Retort carbon)	4	4	9	>12	5·5	4·0
51B	Leicester.	4	4	9	9	5·0	11·5
1	S. Wales.	4	4	12	12	4·5	5·5
18F	S. Yorks.	4	4	10	9	4·0	9·0
26B	S. Yorks.	4	4	12	10	8·5	3·5
3F (II)	S. Yorks.	4	4	9	9	0·5	7·5
29E	S. Yorks.	4	4	8	8	2·5 †	11·0
17B	S. Yorks.	4	5	10	9	2·5	4·0
3A	S. Yorks.	4	5	12	9	5·5	1·5
29K	S. Yorks.	4	5	10	9	6·0	3·5
52	(Artificial graphite)	5	4	9	>12	6·5	1·5
3E (I)	S. Yorks.	5	4	12	11	1·5	5·5
29C	S. Yorks.	5	4	11	11	0·5	2·5
40A	Lancs.	5	4	9	8	2·5	7·5
37	S. Yorks.	5	4	9	9	2·0	8·0
29G	S. Yorks.	5	4	9	9	0·5	3·5
18J	S. Yorks.	5	4	10	8	3·0	13·0
31A	S. Yorks.	5	4	10	10	1·5	2·5
18C	S. Yorks.	4	6	12	9	6·0	0·5
20B	Cumb.	4	6	12	12	3·5	0·5
23A	Durham.	4	6	12	12	3·5	1·0
17E	S. Yorks.	4	6	10	11	6·5	1·0
29B	S. Yorks.	4	6	11	11	2·5	0·5
29J	S. Yorks.	4	6	11	9	4·5	1·5
17C	S. Yorks.	5	5	>12	11	0·5	0·5
3E (VI)	S. Yorks.	5	5	>12	10	0·5	1·5
3E (VIII)	S. Yorks.	5	5	10	10	1·0	0·5
43	S. Wales.	5	5	10	9	2·0	2·0
5	Durham.	5	5	11	8	2·5	0·5
18E	S. Yorks.	5	5	11	10	4·5	0·0
22B	Derby.	5	5	11	11	0·5	0·5
21A	Cumb.	5	6	12	11	1·0	0·5
19B	S. Yorks.	5	6	>12	11	0·5	3·0
3B	S. Yorks.	5	6	12	12	2·0	0·5
3F (I)	S. Yorks.	5	6	9	10	1·5	0·5
3C	S. Yorks.	5	7	>12	12	0·5	0·5
17K	S. Yorks.	6	3	11	11	0·0	0·5
2	Durham.	6	4	12	10	0·5	2·5
3E (V)	S. Yorks.	6	4	>12	12	0·5	5·0
14	S. Wales.	6	4	11	8	0·5	4·5
17A	S. Yorks.	6	4	12	10	1·0	0·5
18A	S. Yorks.	6	4	11	9	3·5	4·0
20A	Cumb.	6	4	12	12	0·5	3·5
28B	Derby	6	4	11	10	0·5	2·5
6	Durham.	6	5	11	12	0·5	1·5
15	Derby.	6	5	11	8	1·5	0·5
8A, B	S. Wales.	6	5	9	8	1·0	0·5
29F	S. Yorks.	6	6	10	9	1·5	0·5
28D	Derby.	6	6	12	12	0·5	0·5
28E	Derby.	6	6	11	9	0·5	0·5
30A	Durham.	6	6	9	10	0·5	1·0
30B	Durham.	6	6	12	12	3·0	1·0
39	S. Wales.	6	6	>12	>12	2·0	1·0
16	Lancs.	6	6	11	10	0·5	0·5
18B	S. Yorks.	6	6	12	9	0·5	0·5
3D	S. Yorks.	6	6	>12	>12	0·5	0·5
21B	Cumb.	6	6	12	11	0·5	0·5
22D	Derby.	6	6	11	10	0·5	0·5
28A	Derby.	6	6	11	11	0·5	0·5
28C	Derby.	7	7	10	9	0·5	0·5

* Per cent. at 6 in. level.

† Per cent. at 3 in. level.

Coke No.	Origin.	Height of Bed for 20 per cent. CO (in.). 2nd set.	1st set.	Remarks.
29J	S. Yorks.	11	9	Blend with 20 per cent. low-temperature coke.
3E (VIII)	S. Yorks.	10	10	
43	S. Wales.	10	9	Blend with steam coal.
5	Durham.	11	8	
3F (I)	S. Yorks.	9	10	
14	S. Wales.	11	8	Blend with steam coal.
18A	S. Yorks.	11	9	
15	Derbyshire.	11	8	Blend with poorly-caking coal.
8AB	S. Wales.	9	8	Blend with 14 per cent. anthracite.
29F	S. Yorks.	10	9	Blend with poorly-caking coal.
28E	Derbyshire.	11	9	Poorly-caking coal.
30A	Durham.	9	10	
28C	Derbyshire.	10	9	Poorly-caking coal.

Of these thirteen cokes, eight were made from charges containing poorly-caking materials.

The general deduction previously made from these tests can therefore be amplified, and it may be said that the addition of non-caking or poorly-caking material to a strongly-caking coal increases the reactivity of the resultant coke with both oxygen and carbon dioxide.

With regard to the formation of carbon monoxide within a short distance from the grate, Table XLV shows that the mean percentage at the 4-in. level with the more reactive group of cokes is 5·3, a percentage as low as 1·5 (mean of both sets of analyses) being found with but one coke (No. 29C). With the less reactive group, a percentage of carbon monoxide of more than 1·5 is rare at the 4-in. level unless all the oxygen has disappeared at that level. The relationship between the disappearance of oxygen and the formation of carbon monoxide is clear. In general, traces only of carbon monoxide are formed, whilst the air-blast still contains oxygen. Carbon dioxide is, therefore, the predominant product of the primary reactions between air and lump coke at high temperatures.

The Maximum Temperature of Combustion. In all the tests, the maximum temperature of combustion was developed within the oxidising zone, usually near the upper limit of that zone. It varied between 1800° C. and 1560° C., being highest with a Yorkshire beehive coke and lowest with wood charcoal. In general, high-combustion temperatures were given with what are regarded as "good" blast-furnace cokes and low temperatures with "poor" cokes.

When the cokes are arranged, as in Table XLVI, in descending order of their maximum combustion temperatures, it is evident that the highest temperatures are not necessarily, or even generally, produced by the most reactive cokes. Twelve only of the "more reactive group," but as many as twenty-six of the " less reactive group " produced temperatures of 1700° or more. The so-called " law of heat compression " propounded, on theoretical grounds, by Korevaar (" Combustion in the Gas Producer and the Blast Furnace." London, 1924) is not supported by these tests. Theoretically, according to Korevaar, there should be a smaller combustion zone with the more reactive cokes and, in consequence, a greater concentration of heat in that zone.

Other properties of the cokes listed in Table XLVI, in an attempt to trace some relationship with the maximum combustion temperature, are the real specific gravity, the percentage total porosity and the percentage of open pores. Because their ash contents differed so widely, the real specific gravities of the cokes have been calculated on an ash-free basis, so that the figures relate to the pure " coke carbon " and are strictly comparable. The ash was assumed to have a specific gravity of 2·5. The cokes having the highest real specific gravities, calculated in this way, give, in general, the highest combustion temperatures. There are many exceptions for which, with our present limited knowledge, it would be idle to attempt more than a general explanation.

When the exceptions are analysed, it appears that those cokes (twenty out of thirty-eight) which give a maximum combustion temperature of 1700° C. or more, but have a low specific gravity (less than 1·85), are mostly " blend " cokes, from blends of good caking coals with non-caking or poorly-caking materials, or cokes made from " hards." The internal structure of such cokes differs from the normal. At the other end of the scale, forty-two cokes developed a maximum combustion temperature of less than 1700° C. Of these, only eleven had a real specific gravity of 1·85 or more. The reason for these eleven " exceptions " can, at present, only be surmised. A surprising exception is No. 52, artificial graphite, which, with wood charcoal, gave the lowest temperatures of the series.

Average Temperature of the Fuel Bed. In those industrial operations, such as crucible steel melting, in which a high temperature in a comparatively small zone is required, the maximum combustion temperatures recorded in our tests are no doubt of prime importance in assessing the value of the cokes. From the results of our tests, it can be understood why crucible steel melters prefer beehive cokes to by-product cokes. For other purposes, in particular for blast-furnace work, the maximum combustion temperature is perhaps not so important as the average fuel-bed temperature. For example, Johnson (" Principles, Operation and Products of the Blast Furnace." New York, 1918) has pointed out that at the hearth a fairly extensive zone at a temperature greater than the free-running temperature of the slag (about 1500 to 1550° C.) is essential. The average temperature of combustion of the coke within a radius of several feet is therefore of importance.

It has already been observed that the rate of combustion of coke is dependent mainly on the rate at which oxygen can be supplied to

TABLE XLVI.—COKES IN ORDER OF MAXIMUM TEMPERATURE OF FUEL-BED.

Coke No.	Origin.	Maximum Temperature (° C.).	Real Sp. Gravity (ash-free basis).	Per cent. Total Porosity.	Per cent. Open Pores.	Remarks.
3D	S. Yorks.	1800	1·88	56·2	40·0	72-hr. beehive coke.
3C	S. Yorks.	1790	1·88	59·2	47·0	48-hr. beehive coke.
21A	Cumb.	1790	1·91	51·8	36·8	
20A	Cumb.	1775	1·91	55·6	39·2	
17M	S. Yorks.	1750	2·07	14·7	12·2	Retort carbon from oven walls.
30B	Durham.	1750	1·95	56·0	43·1	
3F (II)	S. Yorks.	1750	1·88	56·8	43·8	
29M	S. Yorks.	1740	1·78	43·7	35·8	Blended with 30 per cent. anthracite.
3B	S. Yorks.	1740	1·88	52·3	43·0	
17C	S. Yorks.	1730	1·77	46·6	33·2	Made from ground hards (Parkgate).
19B	S. Yorks.	1725	1·85	54·0	44·9	14-in. oven coke.
29J	S. Yorks.	1720	1·83	56·9	49·7	Blended with 20 per cent. low-temperature coke.
3E (VIII)	S. Yorks.	1720	1·86	47·4	30·4	
28C	Derby.	1720	1·73	47·0	34·2	Poorly-caking coal (Deep Hard).
20B	Cumb.	1710	1·84	50·8	34·9	
43	S. Wales.	1710	1·88	52·0	35·5	Blended with steam coal.
3F (I)	S. Yorks.	1710	1·88	54·6	35·4	
28A	Derby.	1710	1·78	49·7	36·5	
27B	S. Yorks.	1710	1·74	37·9	29·6	Made from lumps of Barnsley hards.
22B	Derby.	1710	1·76	48·0	29·8	Blend of poor caking coals (Deep Soft and Barnsley).
25B	S. Wales.	1710	1·79	35·9	33·0	Blended with 33 per cent. anthracite and 33 per cent. steam coal.
17D	S. Yorks.	1710	1·70	48·6	36·1	Made from ground Barnsley hards.
26B	S. Yorks.	1710	1·83	52·1	42·4	Blend containing poorly-caking coals (Lidgett, Barnsley, Kent Thick).
2	Durham.	1710	1·78	53·8	—	
1	S. Wales.	1700	1·77	51·3	46·8	Blended with steam coal.
18A	S. Yorks.	1700	1·86	58·9	48·6	14-in. oven coke.
31A	S. Yorks.	1700	1·95	53·8	41·9	72-hr. beehive coke.
17B	S. Yorks.	1700	1·85	45·8	37·9	
23A	Durham.	1700	1·87	48·2	44·0	
8A, B	S. Wales.	1700	1·82	41·5	34·5	Blended with 14 per cent. anthracite.
18J	S. Yorks.	1700	1·77	50·5	44·1	Blended with 32 per cent. poorly-caking coal (Barnsley).
14	S. Wales.	1700	1·81	50·8	39·1	Blended with steam coal.
16	Lancs.	1700	1·87	53·1	35·4	
21B	Cumb.	1700	1·86	51·0	36·7	
18F	S. Yorks.	1700	1·80	55·6	46·3	
3E (VI)	S. Yorks.	1700	1·88	55·2	41·1	
6	Durham.	1700	1·82	53·7	39·1	
18C	S. Yorks.	1700	1·81	50·3	42·9	
28B	Derby.	1695	1·79	51·3	37·8	Poorly-caking coal (Tupton).
28E	Derby.	1695	1·70	48·3	37·1	Poorly-caking coal (Waterloo).
17G	S. Yorks.	1690	1·81	56·2	39·8	
18E	S. Yorks.	1690	1·76	54·4	45·9	
3G (I)	S. Yorks.	1690	1·71	46·3	35·9	Poorly-caking coal (Barnsley, Wath Wood, High Hazel).
22F	Derby.	1690	1·73	52·7	40·9	Poorly-caking coal (Deep Soft, etc.).
22D	Derby	1690	1·75	49·7	36·7	Poorly-caking coal (Deep Soft).
3A	S. Yorks.	1685	1·88	51·5	30·5	Blended with 28 per cent. poorly-caking coal.
4	S. Yorks.	1685	1·82	46·3	34·9	Blended with poorly-caking coal.
3E (V)	S. Yorks.	1680	1·90	58·2	46·6	
37	S. Yorks.	1680	1·71	48·6	35·1	Made from poorly-caking coal (Barnsley).
17F	S. Yorks.	1680	1·76	50·2	40·6	Made from lumps of ground Swallow Wood hards.
39	S. Wales.	1670	1·93	57·5	45·8	
25A	S. Wales.	1670	1·76	40·0	35·1	Blended with 67 per cent. anthracite.
29B	S. Yorks.	1670	1·80	54·2	45·3	
29A	S. Yorks.	1670	1·81	45·4	35·1	
29K	S. Yorks.	1670	1·81	46·2	32·3	Blended with 20 per cent. low-temperature coke.
29E	S. Yorks.	1670	1·76	54·3	42·7	Poorly-caking coal (Wath Wood, Swallow Wood).
38A.s	S. Yorks.	1670	1·72	55·9	43·5	Made from washed slurry from poorly-caking coal.
40A	Lancs.	1670	1·80	44·6	28·2	
3E (I)	S. Yorks.	1670	1·93	51·5	34·1	Made from 1 to 1½ in. coal.
29F	S. Yorks.	1665	1·88	54·2	41·6	Blended with 20 per cent. poorly-caking coal (No. 29D).
3E (II)	S. Yorks.	1660	1·88	51·5	36·6	Made from ½ to ⅜ in. coal.
29O	S. Yorks.	1660	1·76	39·0	31·2	Blended with 20 per cent. anthracite.
17I	S. Yorks.	1660	1·91	56·1	41·1	
17A	S. Yorks.	1650	1·88	51·5	45·1	
5	Durham	1650	1·81	41·0	31·9	
29C	S. Yorks.	1650	1·83	55·0	37·5	14-in. oven coke.
15	Derby.	1650	1·72	48·0	33·5	Blended with poorly-caking coal (Tupton, Deep Hard).
13B (b)	S. Yorks.	1650	1·67	43·2	33·5	Blended with 30 per cent. ground hards.
18B	S. Yorks.	1650	1·85	51·3	40·3	
28D	Derby.	1645	1·71	46·4	35·6	Poorly-caking coal (Deep Soft).
29G	S. Yorks.	1640	1·85	54·6	36·9	Blended with 20 per cent. poorly-caking coal (No. 29D), 14-in. oven.
30A	Durham.	1635	1·80	49·3	40·0	
29D	S. Yorks.	1630	1·74	52·7	44·2	Poorly-caking coal (Wath Wood and Swallow Wood).
51B	Leicester.	1630	1·67	53·2	47·7	Non-caking coal briquetted with pitch.
17H	S. Yorks.	1630	1·75	57·2	50·5	
17K	S. Yorks.	1625	1·83	46·8	35·0	
22G	Derby.	1620	1·72	50·6	42·6	Blended with 20 per cent. low-temperature coke.
17E	S. Yorks.	1590	1·71	58·0	47·7	Made from poorly-caking coal (Swallow Wood).
53		1560	1·40	61·8	39·1	Wood charcoal.
52		1560	2·14	28·4	16·0	Artificial graphite (from electrodes).

TABLE XLVII.—AVERAGE TEMPERATURES OF THE FUEL-BED (1½ to 10½ in. levels).

Coke No.	Origin.	Average Temp. (° C.).	Max. Temp. (° C.).	Real Sp. Gravity (ash-free basis).	Per cent. Total Porosity.	Shatter Index (1½ in.).	Remarks.
2	Durham.	1635	1700	1·78	53·8	90	
17M	S. Yorks.	1605	1750	2·07	14·7	96	Retort carbon.
6	Durham.	1605	1675	1·82	53·7	93	
3D	S. Yorks.	1600	1790	1·88	56·2	85	72-hr. beehive coke.
29M	S. Yorks.	1600	1740	1·78	43·7	90	Blended with 30 per cent. anthracite.
20A	Cumb.	1595	1775	1·91	55·6	88	
20B	Cumb.	1590	1710	1·84	50·8	80	
18A	S. Yorks.	1590	1700	1·86	58·9	80	14-in. oven coke.
3B	S. Yorks.	1585	1740	1·88	52·3	83	
31A	S. Yorks.	1585	1700	1·95	53·8	92	72-hr. beehive coke.
29J	S. Yorks.	1580	1720	1·83	56·9	89	Blended with 20 per cent. low-temperature coke.
43	S. Wales.	1580	1710	1·88	52·0	96	Blended with steam coal.
17B	S. Yorks.	1580	1700	1·85	45·8	82	
1	S. Wales.	1575	1700	1·77	51·3	97	
39	S. Wales	1570	1675	1·93	57·5	97	
21A	Cumb.	1570	1790	1·91	51·8	77	
3E (VIII)	S. Yorks.	1565	1720	1·86	47·4	89	
3F (I)	S. Yorks.	1565	1710	1·91	54·6	91	
23A	Durham.	1565	1700	1·87	48·2	91	
17G	S. Yorks.	1565	1690	1·81	56·2	82	
3G (I)	S. Yorks.	1565	1690	1·71	46·3	88	Poorly-caking coal.
18J	S. Yorks.	1565	1700	1·77	50·5	84	Blended with 32 per cent. poorly-caking coal.
3E (VI)	S. Yorks.	1565	1700	1·88	55·2	88	
14	S. Wales.	1560	1700	1·81	50·8	96	Blended with steam coal.
16	Lancs.	1560	1700	1·87	53·1	83	
22D	Derby.	1560	1680	1·75	49·7	67	Poorly-caking coal (Deep Soft).
30B	Durham.	1555	1750	1·95	56·0	95	
22B	Derby.	1555	1700	1·76	48·0	66	Poorly-caking coal blend.
22F	Derby.	1555	1690	1·73	52·7	74	Poorly-caking coal.
21B	Cumb.	1555	1700	1·86	51·0	75	
3C	S. Yorks.	1555	1790	1·88	59·2	84	48-hr. beehive coke.
29G	S. Yorks.	1555	1640	1·85	54·6	83	Blended with 20 per cent. poorly-caking coal (29D).
3E (V)	S. Yorks.	1555	1680	1·90	58·2	86	
4	S. Yorks.	1555	1675	1·82	46·3	80	
8A, B	S. Wales.	1550	1700	1·82	41·5	91	Blended with 14 per cent. anthracite.
17C	S. Yorks.	1550	1730	1·77	46·6	85	Made from ground hards (Parkgate).
17F	S. Yorks.	1550	1670	1·76	50·2	70	Made from ground Swallow Wood hards.
17D	S. Yorks.	1545	1710	1·70	48·6	86	Made from ground Barnsley hards.
28A	Derby.	1545	1710	1·78	49·7	67	
25B	S. Wales.	1545	1700	1·79	35·9	87	Blended with 33 per cent. anthracite and 33 per cent. steam coal
17A	S. Yorks.	1545	1650	1·88	51·5	90	
3E (I)	S. Yorks.	1545	1665	1·93	51·5	66	
30A	Durham.	1545	1635	1·80	49·3	93	
3F (II)	S. Yorks.	1540	1750	1·88	56·8	92	
19B	S. Yorks.	1540	1725	1·85	54·0	82	
29B	S. Yorks.	1540	1670	1·80	54·2	87	
29F	S. Yorks.	1540	1665	1·88	54·2	86	Blended with 20 per cent poorly-caking coal (29D).
3E (II)	S. Yorks.	1535	1660	1·88	51·5	68	
3A	S. Yorks.	1535	1675	1·88	51·5	86	
27B	S. Yorks.	1530	1710	1·74	37·9	80	Made from lumps of Barnsley hards.
29O	S. Yorks.	1520	1660.	1·76	39·0	74	Blended with 30 per cent. anthracite.
5	Durham.	1520	1650	1·81	41·0	85	
29D	S. Yorks.	1520	1630	1·74	52·7	80	Poorly-caking coal.
28C	Derby.	1515	1720	1·73	47·0	85	Poorly-caking coal (Deep Hard).
17I	S. Yorks.	1515	1660	1·91	56·1	73	
29C	S. Yorks.	1510	1650	1·83	55·0	85	
29A	S. Yorks.	1510	1670	1·81	45·4	79	
18C	S. Yorks.	1505	1675	1·81	50·3	77	
29K	S. Yorks.	1505	1670	1·84	46·2	88	Blended with 20 per cent. low-temperature coke.
29E	S. Yorks.	1500	1670	1·76	54·3	81	Poorly-caking coal.
40A	Lancs.	1500	1640	1·80	44·6	89	
17K	S. Yorks.	1500	1605	1·83	46·8	89	
18B	S. Yorks.	1500	1590	1·85	51·3	84	
18F	S. Yorks.	1495	1700	1·80	55·6	89	Made from washed slurry from poorly-caking coal.
38A.s	S. Yorks.	1490	1670	1·72	55·9	89	
18E	S. Yorks.	1485	1630	1·76	54·4	84	
28E	Derby.	1485	1695	1·70	48·3	72	Poorly-caking coal (Waterloo).
17H	S. Yorks.	1475	1620	1·75	57·2	79	
28D	Derby.	1475	1645	1·71	46·4	72	Poorly-caking coal (Deep Soft).
26B	S. Yorks.	1475	1670	1·83	52·1	76	Blend containing poorly-caking coals.
25A	S. Wales.	1470	1675	1·76	40·0	84	Blended with 67 per cent. anthracite.
15	Derby.	1470	1650	1·72	48·0	66	Blended with poorly-caking coal.
37	S. Yorks.	1465	1620	1·71	48·6	62	Poorly-caking coal (Barnsley).
22G	Derby.	1460	1610	1·72	50·6	79	Blended with 20 per cent. low-temperature coke.
13B(*b*)	S. Yorks.	1455	1650	1·67	43·2	80	Blended with 20 per cent. ground Parkgate hards
17E	S. Yorks.	1440	1590	1·71	58·0	73	Poorly-caking coal (Swallow Wood).
28B	Derby.	1430	1650	1·79	51·3	72	Poorly-caking coal (Tupton).
52		1430	1560	2·14	28·4	90	Artificial graphite
51B	Leicester	1425	1630	1·67	53·2	95	Non-caking coal briquetted with pitch.
53		1425	1560	1·40	61·8	—	Wood charcoal

it and that the intensity of combustion bears no direct relation to the "reactivity" of the coke with oxygen. In general, under the conditions of our tests the less reactive cokes gave the highest combustion temperatures. The reaction of coke with carbon dioxide, an endothermic reaction, lowers the fuel-bed temperature, so that, other things being equal, the highest average fuel-bed temperatures should be produced by the cokes that are the less reactive with both oxygen and carbon dioxide.

In Table XLVII the average fuel-bed temperatures observed during our tests are recorded, the temperature of the topmost $1\frac{1}{2}$ in. being omitted, since it was subject to variation with slight changes in the experimental conditions. The "second set" of temperature determinations, when the condition of the fuel-bed was most constant, have been chosen, and the "maximum" temperatures also recorded in Table XLVII relate to that set of determinations. The average temperatures range from about 1600° C. to about 1400° C. To attain the same hearth temperature, the cokes at the foot of the table would have to be burnt at a faster rate than those at the head, and would therefore be less economical.

From a study of the general properties of the cokes we have tested, it appears that the average temperature of the fuel-bed is lower the lower the impact hardness, real specific gravity and total porosity of the coke.

THE COMBUSTION OF A STANDARD SIZE OF COKE WITH DIFFERENT RATES OF SUPPLY OF AIR

A number of cokes were burnt with different rates of supply of air, such that approximately (1) 13, (2) 26, (3) 39, (4) 52 and (5) 65 lb. of coke were burnt per sq. ft. of grate area per hour. Some of the results are recorded in Table XLVIII.

TABLE XLVIII.—THE COMBUSTION OF STANDARD SIZE COKE WITH DIFFERENT RATES OF SUPPLY OF AIR.

(A). *Distance from Grate (in.) at which Oxygen disappeared.* (2nd Set/1st Set.)

Coke No.	1.	2.	3.	4.	5.	6.
Rate No.						
1	6/6	4/4	4/4	–/4	6/4	6/6
2	4/4	3/6	6/4	3/3	5/3	5/5
3	4/4	6/4	4/5	3/5	5/5	6/5
4	6/6	—	—	—	—	6/7
5	—	—	—	—	—	6/6

(B.) *Distance from Grate (in.) at which Carbon Monoxide reached 20 per cent.* (2nd Set/1st set.)

Coke No.	1.	2.	3.	4.	5.	6.
Rate No.						
1	9/10	–/12	7/8	–/8	–/8	12/12
2	10/8	12/8	11/8	–/8	12/8	12/9
3	12/12	12/10	12/9	7/8	12/8	11/>12
4	>12/10	—	—	—	—	12/12
5	—	—	—	—	—	>12/>12

(C.) *Maximum Temperature* (°C.) *in Fuel-bed.* (2nd Set/1st Set.)

Coke No. Rate No.	1.	2.	3.	4.	5.	6.
1	1685/1685	1585/1600	1560/1500	—/1540	1510/1510	1560/1485
2	1680/1695	1710/1710	1710/1660	1710/1640	1535/1560	1610/1610
3	1710/1710	1710/1620	1685/1685	1685/1685	1635/1660	1685/1710
4	1760/1760	—	—	—	—	1735/1735
5	—	—	—	—	—	1735/1760

(D). *Average Temperature* (°C.) *of Fuel-bed.* (2nd Set).

Coke No. Rate No.	1.	2.	3.	4.	5.	6.
1	1395	1390	1365	—	1320	1380
2	1545	1620	1540	1555	1415	1490
3	1575	1635	1535	1555	1520	1605
4	1600	—	—	—	—	1645
5	—	—	—	—	—	1645

In conformity with Kreisinger's (*loc. cit.*) experiments, in which the rate of combustion was varied between about 20 and 120 lb. per sq. ft. per hour, these results show that increasing the air supply has but little effect on the distance from the grate at which the oxygen of the blast disappears, or on the distance at which the reduction of carbon dioxide is complete. The main effect of increasing the air supply is to increase the rate of combustion of the coke. As a consequence, the maximum temperature of combustion and the average fuel-bed temperature tend to rise as the air-supply is increased.

THE COMBUSTION OF DIFFERENT SIZES OF COKE WITH THE SAME RATE OF SUPPLY OF AIR

A number of experiments have been made on the combustion of different sizes of coke with the same rate of supply of air. Some of the results are recorded in Table XLIX.

The size of the coke is seen to have a considerable effect on its reactivity with both oxygen and carbon dioxide, and to affect also the temperature of combustion. As between one coke and another (of the same size) of the many varieties tested, the greatest difference in height of the oxidising zone was about 4 in. Such a difference is obtained by varying the size of the coke pieces by 1 in. only, between the limits ½ in. and 1½ in. No doubt increase in the size of the coke pieces above 2 in. would increase the extent of the oxidising zone still further. The size of the coke pieces fed to a blast furnace can therefore be expected to influence considerably the size of the oxidising zone, and thus, as Royster and Joseph have shown (*Trans. Amer. Inst. Min. Met. Eng.*, 1924, **73**, 224), to affect the stock descent. Presumably, with a coke liable to fracture into small pieces the burden would tend to fall near the furnace lining; whilst with a coke which produces large pieces on fracture the stock movement would extend more towards the centre of the furnace.

So far as the maximum temperature of combustion is concerned, our tests do not indicate that the smaller sizes of coke would produce

Table XLIX.—The Combustion of Different Sizes of Coke with the Same Rate of Supply of Air.

		Size of Coke.		
		2 to 1½ in.	1½ to 1 in.	1 to ½ in.
Coke No. 43 (S. Wales)	Distance from grate (in.) at which oxygen disappeared (2nd set/1st set)	8/8	5/5	3/4
	Distance from grate (in.) at which carbon monoxide reached 20 per cent. (2nd set/1st set)	>12/>12	10/9	6/5
	Maximum temperature (° C.) in fuel-bed (2nd set/1st set)	1690/1710	1710/1665	1725/1690
	Average temperature (° C.) of fuel-bed (2nd set)	1610	1575	1555
Coke No. 4 (S. Yorks.)	Distance from grate (in.) at which oxygen disappeared (2nd set/1st set)	—	3/5	3/3
	Distance from grate (in.) at which carbon monoxide reached 20 per cent. (2nd set/1st set)	—	7/8	6/6
	Maximum temperature (° C.) in fuel-bed (2nd set/1st set)	—	1685/1685	1585/1685
	Average temperature (° C.) of fuel-bed (2nd set)	—	1555	1395

lower temperatures. The average fuel-bed temperature, however, is lower the smaller the size of the coke, no doubt because the smaller coke is more reactive with carbon dioxide. On this account, as well as because it would tend to exaggerate the descent of the stock near the furnace lining, small coke would appear undesirable in the charge. We hope that the future development of our tests will provide information as to the minimum useful size of coke in blast-furnace practice.

The Reactivity of Coke in Blast-furnace Practice

The general conclusions to be drawn from the experimental work here described are :

(1) The specific reactivities of many different cokes, of the same size and burnt with the same rate of supply of air, have been nearly the same. Such differences as have been observed have been due, apparently, to the character of the coal charge from which the coke was made, the presence in the charge of a non-caking or poorly-caking material causing, in general, an increase in the reactivity of the coke.

(2) Under like conditions of burning, cokes having the higher specific reactivities have usually given the lower average fuel-bed temperatures and the lower maximum temperatures of combustion.

(3) With a given coke under standard conditions of burning, an increase in the size of the pieces reduces the specific reactivity and increases the average fuel-bed temperature.

(4) With a coke of given size, an increase in the rate of supply of air for combustion proportionately increased the amount of coke burnt and the average temperature of combustion.

Relating these conclusions to blast-furnace practice, it can be assumed that :

(1) Since the rate of combustion of coke at the tuyeres will depend on the rate of supply of air, and since this, in turn, depends on the resistance of the charge to the passage of gases, the presence of much coke breeze in the furnace will restrict its rate of driving.

(2) The hearth temperature will be reduced by the presence of small coke.

(3) A satisfactory hearth temperature can be most economically maintained with an " unreactive " coke containing but little breeze.

(4) The size of a coke and its hardness affect the hearth conditions more than does its specific reactivity.

APPENDIX

When discussing the question of coke reactivity (p. 117), we remarked that wood charcoal and " meiler " coke, both of which are highly reactive and both of which have a good reputation as blast-furnace fuels, required separate consideration.

As regards wood charcoal, the low fuel consumptions that have been reported when using this fuel have been when smelting rich ores in small furnaces. It would seem that unusual results have been obtained only when the hearth-heat requirements have been low. The ash-content of wood charcoal is low, and not only is the ash self-fluxing, but it provides some flux for silica in the ore. The hearth heat required to deal with the ash of wood charcoal is therefore low, as it is also when smelting a rich and easily reduced ore. Under such conditions the output of a small furnace can be high. Comparison of the performances of charcoal and coke blast-furnaces may therefore be misleading.

" Meiler " cokes have also given the best results when used in small furnaces, whilst with the small Scotch blast furnaces using splint coal the fuel consumption is comparatively low and the output, for the furnace volume, is high.

" Meiler " coke and the coke from Scotch splint coal are lumps similar to those obtained on carbonising lumps of non-swelling " hards," *e.g.* coke No. 27B. This coke produced a high maximum temperature of combustion (1710° C.) on test, but was as reactive with oxygen as wood charcoal under the same conditions of test. A reactive coke made from fine coal usually produces a low maximum temperature on combustion.

CHAPTER IX

THE SPECIFICATION OF COKE

NATURAL results of a knowledge of those properties of coke that are of importance in blast-furnace practice would be its specification and its sale to that specification. By placing a financial value on each of its more important properties, encouragement would be given to the manufacturers of coke to improve its quality. At the present time (1930), the price of coke in the Midland area is related to the price of pig-iron, but coke users are offered, at a uniform price, cokes varying widely in their properties, for example, in their ash-contents and moisture-contents. Blast-furnace operators recognise, however, the advantages of cokes low in ash and moisture, and so hard as to make but little breeze. They also hail certain cokes as "good blast-furnace cokes" without being able to recognise the particular qualities that render them such. It is possible that, when extended, our observations as to the significance of combustion temperatures may help to explain why these cokes are held in such high esteem.

Before discussing the lines on which specifications of cokes could now be drawn up, early specifications for blast-furnace cokes should be considered.

Simmersbach ("Kokschemie," 1914, 2nd ed., 243) suggested the following: Ash, 9; moisture, 5; sulphur, 1 to 1·25; dust (on receipt), 6; porosity, 50; maximum percentages in each instance. Crushing strength, 100 kg. per sq. cm. (1422 lb. per sq. in.); as a minimum.

Koppers ("Taschenbuch für Gaswerke, Kokereien, Schwelereien und Teerdistillation," 1929, Halle (Saale), modified this specification by substituting for "crushing strength" the "hardness" as determined by the Micum trommel and shatter tests, thus: Trommel test index (on 40 mm.), 65 to 70; shatter test index (on 2 in.), 75.

A single rigid specification is, however, of limited value, for local circumstances, as regards both the coke-producing and the coke-using plant, have to be considered. For example, few Yorkshire cokes could meet Simmersbach's specification so far as sulphur content is concerned; whilst, on the other hand, with furnaces making basic iron the slag may be sufficiently basic to allow of the use of cokes containing 2 per cent. or more of sulphur (see Bolling, *Iron Age*, 1908, 1262). Greater use could be made of a specification in which a value was placed on each of the more important properties of coke and a sliding-scale basis of payment adopted, with bonus and penalty clauses.

THE CHEMICAL PROPERTIES OF COKES IN RELATION TO THEIR SPECIFICATION

The chemical value of a coke to a blast-furnace operator is determined mainly by its carbon-content, for the carbon in coke alone is of value to him by yielding, on combustion, the carbon monoxide and heat necessary to reduce the ore and to melt the metal and slag produced.

It is convenient * to consider the blast-furnace value of a coke on a thermal basis. As the amounts of moisture and ash in the coke increase, the amount of carbon and the calorific value decrease, so that a greater weight of coke has to be used to provide the same weight of carbon (or the same number of heat units). For example, if with a coke of 85 per cent. carbon-content the consumption is 30 cwt. per ton of pig (*i.e.*, 3,360 lb. of coke, containing 2,846 lb. of carbon), the consumption with a coke of only 84 per cent. carbon-content will be 40 lb. (0·36 cwt.) greater, for 3,400 lb. of it will be required to provide 2,846 lb. of carbon.

The coke consumption being a given amount with a standard coke, the increased consumption due to the use of a coke of lower carbon-content can be calculated by multiplying by the ratio of the carbon-contents of the two cokes. For example, assume, as before, that the coke consumption with a coke containing 85 per cent. of carbon is 3,360 lb. Then the consumption with a coke of 84 per cent. carbon-content will be $3{,}360 \times \frac{85}{84} = 3{,}400$ lb., an increase of 40 lb. For convenience in calculation, the consumption with the coke of 85 per cent. carbon-content may be assumed to be 2,240 lb. Then the consumption when a coke of 84 per cent. carbon-content is used will be $2{,}240 \times \frac{85}{84} = 2{,}267$ lb., an increase of 27 lb.

The " coke equivalent " of 1 per cent. of " inerts " (*i.e.* moisture and ash) will vary with the standard carbon-content, a decrease of carbon from 80 to 79 (due to an increase of 1 per cent. of " inerts ") demanding a higher coke equivalent than a decrease from 90 to 89. Assuming the coke consumption per ton of pig to be 2,240 lb., the increased coke requirements (C) for a decrease in the carbon-content of the coke of 1 per cent. are calculated in Table L for different standard carbon-contents (S), from the equation $C = \left(2{,}240 \times \frac{S}{(S-1)}\right) - 2{,}240$.

---

* It is not accurate to consider the value of a coke on a thermal basis only, for heat intensity is an important factor. We have shown that the larger sizes of the same coke, burnt under standard conditions, produced the higher average temperatures of combustion. It is possible that with still larger sizes the average temperature of combustion would not further increase. In that event, the calorific value of a coke, for all sizes above a certain minimum, would be significant, but the smaller sizes would have a lower effective calorific value. The blast-furnace tests recorded on page 20, indeed, suggest that coke below a certain size can be considered to have no effective calorific value. The thermal basis is reliable for showing the effect of moisture and ash for a given coke.

TABLE L.—THE INFLUENCE OF MOISTURE AND ASH IN INCREASING COKE CONSUMPTIONS.

Standard Carbon-content of Coke (S).	Increased Coke Requirement (C) for 1 per cent. Reduction in Carbon Content (lb.).	Ratio. $\frac{\text{Increased Coke Requirement}}{\text{Increased "Inerts"}}$
80	29	1·30
85	27	1·20
90	25	1·12
95	23	1·03
100	22	1·00

In the third column of Table L are given, for the different values of S, the ratio of the value of C to the increase in the moisture- and ash-content of the coke (1 per cent., or 22·4 lb.). Unless the carbon-content of the coke is 100 per cent., the percentage increase in the coke consumption is greater than the percentage increase in the amount of "inerts," because the latter is calculated on the coke as a whole and not on the carbon in the coke. It follows that it is not strictly correct to allow for the moisture present in the coke by calculating the dry weight of coke charged, unless the moisture is expressed as a percentage of the carbon present. Thus, 10 per cent. of moisture in a coke of 80 per cent. carbon-content is equivalent to 12·5 per cent. of moisture on the carbon, and 12·5 per cent. should be deducted from the weight of coke charged to allow for the decrease in carbon-content due to the moisture.

Moisture and ash have so far been considered together as "inerts," inasmuch as they both reduce the carbon-content of the coke. They are not merely "inert," however, but both require heat for their removal from the blast furnace.

Moisture in the coke is converted into steam and superheated to the temperature of the top gases. For a top temperature of 450° F., each 1 per cent. of moisture requires for its removal heat equivalent, roughly, to about 0·1 per cent. of the coke charged. This can be ignored.

Ash in the coke must be neutralised and the slag so formed melted. The heat required to decompose the limestone necessary to neutralise the ash, and to melt the slag formed, will vary with the silica- and lime-contents of the ash and the basicity of the slag. Neglecting the lime, the amounts of slag formed from each 1 per cent. of ash of different silica-contents, for two selected basicities of slag, are :

Silica in Ash (per cent.).	Slag formed per 1 per cent. of Ash.	
	Basicity 1·5.	Basicity 1·7.
35	34·1 lb.	35·7 lb.
40	35·8	37·6
45	37·7	39·7

The carbon required to decompose the limestone for 1 lb. of slag and to melt that slag has been calculated by different authorities, thus :

Authority.	Carbon Required per lb. of Slag.
Evans and Bailey *	0·28 lb.
Scott †	0·225
Deladrière ‡	0·30
Lilot §	0·28
Clements‖	0·30
Johnson ¶	0·28

* *Journ. Iron and Steel Inst.*, 1928, **117**, 82.
† Amer. Inst. Min. Met. Eng. Tech. Publication No. 159-C, 21, F. 20, 1929.
‡ *Rev. Univ. des Mines*, 1921, **9**, 93.
§ *Rev. Univ. des Mines*, 1926, **10**, 39.
‖ "Blast Furnace Practice," Vol. I, p. 206. London, 1929.
¶ "Principles, Practice and Operation of the Blast Furnace," p. 73. New York, 1918. (Johnson's figure is given as 0·33 lb. of coke per lb. of slag, the coke being assumed to contain 85 per cent. carbon. Johnson states that the figure commonly adopted is 0·25 lb. of coke per lb. of slag.)

The carbon requirements here listed have sometimes been expressed as heat units. To convert the heat units into their carbon equivalent, it has been assumed that the combustion of the carbon is exclusively to carbon monoxide, the carbon requirements being thus considered as hearth heat requirements only.

Taking a value of 0·29 lb. of carbon, the coke equivalents for cokes of 90, 85 and 80 per cent. carbon-content are 0·32, 0·34 and 0·36 lb. per lb. of slag. The coke requirements for 1 per cent. of ash of 40 per cent. silica-content, converted into slag of 1·5 basicity (35·8 lb. of slag per ton of coke) are, therefore, 11·5, 12·2 and 12·9 lb., for cokes of 90, 85 and 80 per cent. carbon-content.

The gross effect of 1 per cent. (22·4 lb.) of moisture and ash, (*a*) in reducing the carbon-content of the coke and (*b*) in using carbon for their removal from the blast furnace, can be summarised as follows :

Moisture.

Carbon-content of Coke (per cent.).	Increased Coke Requirement for a Decrease of 1 per cent. Carbon.			Per cent. Increased Coke Requirement for 1 per cent. Moisture.
	lb.	or	cwt.	
80	29		0·26	1·30
85	27		0·24	1·20
90	25		0·22	1·12

Ash.

Carbon-content of Coke per cent.).	Increased Coke Requirement for a Decrease of 1 per cent. Carbon due to an Increase of 1 per cent. Ash.			Per cent. Increased Coke Requirement for 1 per cent. Ash.
	lb.	or	cwt.	
80	29 + 12·9 = 41·9		0·37	1·87
85	27 + 12·2 = 39·2		0·35	1·75
90	25 + 11·5 = 36·5		0·33	1·63

A round figure of 2 per cent. of coke for each 1 per cent. of ash has been proposed by Committee No. 2 of the Iron and Steel Institute (*Journ. Iron and Steel Inst.*, 1929, **119**, 50).

When attempting to assess the total cost to the blast-furnace plant of the moisture and ash in coke, the cost of limestone has to be considered, when extra flux is required, and the cost of transport. When estimating a cash allowance for moisture and ash in a blast-furnace coke, a price of 19*s*. per ton delivered at the plant can be assumed, the transport cost (included) being 2*s*. 6*d*. per ton. For each 1 per cent. of ash, 2 per cent. of the total coke price amounts to 4·36*d*. and 1 per cent. of the transport cost to 0·6*d*., making a total of about 5*d*. With limestone at 5*s*. per ton, the amount required per ton of coke to flux 1 per cent. of ash would cost about 0·6*d*.

In addition, consideration can be given to the cash equivalent of the ash-content of the coke with respect to overhead expenses, the output of iron and the quality of the pig. Several experimenters have attempted to include these when determining, in blast-furnace trials, the coke equivalent of 1 per cent. of ash.

For example, Derclaye (*Rev. Univ. des Mines*, 1922, **18**, 345) in a series of trials extending over six years at Ougrée-Marihaye, determined the effect of substituting increasing amounts of coke made from washed coal for coke made from unwashed coal. In one series, in which cokes containing 19·0 and 10·6 per cent. of ash were used during successive periods of 10 to 12 days, the saving with the coke of low ash-content amounted to 5·6 cwt. per ton of pig (or 0·67 cwt. for each 1 per cent. of ash). In one blast furnace increasing proportions of "washed" coke were used during four successive years. The average coke consumptions were 24·1, 21·5, 20·7 and 19·4 cwt. per ton of pig with ash-contents of the coke in successive years of 16·1, 11·9, 10·5 and 10·5 per cent. (or about 0·6 cwt. of coke for each 1 per cent. of ash). Simultaneously, the output of iron increased, the quality of the pig improved, the blast pressure dropped and the furnace-top temperature decreased.

Similar experiments, with "unwashed" and "washed" cokes were made on four furnaces over a number of years. Typical results for one year's working with each type of coke showed the average consumptions to be 24·7 and 20·7 cwt. per ton of pig, equivalent to 0·47 cwt. of "unwashed" coke for each 1 per cent. of ash.

The "washed" coke cost 26 fr. per ton, as compared with 22 fr. for the "unwashed," so that the net saving on coke costs by using the washed coke amounted to 0·3 fr. per ton of pig. The improved quality of the pig for basic open-hearth furnaces, by reason of its lower silicon-content, was estimated to be worth 0·5 fr. per ton. Decreased labour costs (despite an increase in wage rates), because of greater output of the furnaces, was equivalent to 0·8 fr. per ton. General charges on the plant were reduced by 0·5 fr. per ton. The total saving by using "washed" coke was thus estimated to be 2·1 fr. per ton of pig, or 1*s*. 8*d*., pre-war rate of exchange.

To enable the saving by using coke of low ash-content to be evaluated without taking into consideration an increased cost of the coke (which amounted to 3*s.* 4*d.* per ton), Derclaye's results can be considered thus: the reduction in coke consumption of 0·47 cwt. per ton of pig for each 1 per cent. of ash (taking a coke containing 19 per cent. of ash as the basis) represents a carbon equivalent of about 0·36 cwt., the coke, assumed to contain an additional 5 per cent. of "inerts," having a carbon content of 76 per cent. The coke equivalent with a coke containing 85 per cent. of carbon would thus be 0·42 cwt. per ton of pig for each 1 per cent. of ash. Assuming a coke consumption (85 per cent. carbon) of 21·5 cwt. per ton of pig (such as corresponds with Derclaye's results with a coke containing 12 per cent. of ash), the coke equivalent of 1 per cent. of ash per ton of coke used is 0·39 cwt. If the price of the coke is taken at 19*s.* per ton, 0·39 cwt. would be worth about 4·25*d.*, which is about the same (4·3*d.*) as that calculated on theoretical grounds (p. 145).

According to Derclaye, the additional saving per ton of pig for a reduction in ash-content of the coke of 8·4 per cent. would amount to about 1*s.* 6*d.* for a coke consumption of 21·5 cwt., or about 2*d.* for each 1 per cent. of ash. Such additional savings may not always be possible. With Lincolnshire ores, for example, there is no saving in limestone, whilst a reduction in the silicon-content of the pig may not be desirable. Derclaye's results are of interest, however, in showing that there may sometimes be a greater monetary saving than that due to reduction in coke consumption, and in confirming the calculated reduction in consumption consequent on a reduction in the ash-content of the coke by 1 per cent.

In this country, Gill (*Journ. Iron and Steel Inst.*, 1927, **116**, 91) has reported the results of tests, made at the Consett Ironworks, in which cokes of uniform ash-contents were supplied to a number of furnaces during periods of 5 weeks. On replacing a coke containing 12·15 per cent. of ash by one containing 9·8 per cent. (made in the same ovens under the same conditions), the average coke consumption was reduced by 1 cwt. per ton of pig and the output was increased by 15·4 per cent. In another series of tests the substitution of a coke containing 12·5 per cent. of ash by one containing 8·7 per cent. reduced the consumption by 1·76 cwt. per ton of pig and increased the output by 25 per cent., the quality of the pig being improved also.

In these two series of tests, the reduction in coke consumption per ton of pig for a 1 per cent. reduction in the ash-content of the coke was about 0·45 cwt. per ton of coke; this represents a reduction of about 0·4 cwt. (assuming a coke consumption of 22½ cwt. per ton of pig); or of about 0·35 cwt. of carbon with a coke of 85 per cent. carbon-content. This figure is similar to that arrived at by calculation (p. 144). The cash equivalent of the saving in coke consumption effected by Gill amounts to about 4·4*d.* per ton of coke for a reduction of 1 per cent. in the ash-content of the coke (valued at 20*s.* per ton). In the discussion on Gill's paper (*loc. cit.*, p. 98), H. Louis estimated the savings with respect to other charges to amount to 3·5*d.* per ton of coke for each 1 per cent. of ash in the coke.

The general agreement between the calculated savings to be effected by reducing the ash-content of coke and the actual savings obtained in practice is good. The coke equivalent of 1 per cent. of ash appears to lie between 0·3 and 0·4 cwt. per ton of coke used, dependent on the carbon-content of the coke. The monetary equivalent of 1 per cent. of ash per ton of coke is at least 4*d*. The present method of selling coke at a flat rate, which may allow of a variation in ash-content of, say, 3 per cent., thus penalises the producer of a low-ash coke to the extent of at least 1*s*. per ton.

THE HARDNESS OF COKE IN RELATION TO ITS SPECIFICATION

The substitution of a Yorkshire coke by a harder Durham coke, and of a Durham coke by a still harder Westphalian coke, has effected economy in consumption in blast furnaces, cupolas and lime-kilns. The " shatter test " (*q.v.*) enables the hardness of a coke to be assessed. In general, it is preferable when recording the results of this test to state both the 2-in. and the 1½-in. " shatter indices," but for the purposes of coke specifications a single index is desirable. The 1½-in. index is the more reliable for the majority of cokes.

The average value for the 1½-in. shatter index for twenty Yorkshire blast-furnace cokes of commerce is 80, the range covered being 69 to 86. A sliding-scale payment with respect to the hardness of coke could take the average value of 80 as a basis and make a proportionate increase or decrease on the basic price for a higher or a lower shatter index. To allow for variations in the results of individual shatter tests, it would be necessary to carry out, say, at least twenty tests on each coke. The average of the results for a given coke would then assess its hardness as manufactured under standard conditions. Any alteration in those conditions designed to improve the hardness of the coke would call for a retest. To encourage but slight improvements in coke hardness, it would be desirable to have but small units in the scale of payments with respect to hardness, say 2 or 2½ units on the 1½-in. shatter index. As an example of such an arrangement, a basic price of 19*s* per ton for coke of 80 shatter index (1½ in.) as delivered at the blast furnaces may be taken, the sliding scale being :

Coke Hardness (1½-in. Shatter Index).	Price of Coke.		Difference for 2 Units on Shatter Index.
	s.	*d.*	
86	20	4	+ 5*d*.
84	19	11	+ 6*d*.
82	19	5	+ 5*d*.
80	19	0	Basic price
78	18	7	— 5*d*.
76	18	1	— 6*d*.
74	17	8	— 5*d*.

Or a similar scale could be arranged for the price of coke at the ovens, say 16*s*. 6*d*. for a coke of 80 shatter index (1½-in.) with 5*d*. for each two units difference in the index.

Such scales would cover the commercial blast-furnace cokes at present available in Yorkshire and would give a price difference of 2*s.* 6*d.* per ton between the poorest and the best.

OTHER PROPERTIES OF COKE IN RELATION TO ITS SPECIFICATION

The properties of coke so far considered are those the value of which is most readily assessed. The use of a sliding scale of payment with respect to these properties makes their specification unnecessary. Other properties of coke that may affect its value in the blast furnace can be considered briefly.

Sulphur-content. The sulphur-content of coke should be low, if only to avoid reduction of the carbon-content. The average sulphur-content of Yorkshire and Derbyshire cokes is about 1·5 per cent., except when seams such as the Barnsley and the Halifax Soft are used in their manufacture, when the percentage of sulphur may be less than 1. The sulphur-content of the coking slacks used is usually about 1·5 per cent., and this cannot be appreciably reduced. About 0·8 per cent. of the sulphur in the coal is "organic," an integral part of the coal, and the remainder is usually finely-divided pyrites intimately associated with the coal substance.

Porosity. The porosity of a coke appears to be of minor importance in blast-furnace practice. A high value seems to be desirable, but it is probably not worth while to attempt to increase the porosity directly. The adoption of top-charging in place of compressed charges, and the use of faster-coking ovens, tend to increase the porosity of the coke.

Structure. The structure of a coke cannot at present be specified conveniently. It can be demonstrated, and recorded photographically, by means of sections prepared by Rose's method (see p. 53). The structure should be uniform, without enlarged pores, and should reveal few fractures. Improvement in uniformity of structure usually accompanies an improvement in hardness.

Reactivity. The specific reactivity of a coke is of little direct importance in blast-furnace operations, but the development of a high temperature of combustion appears to be desirable. It is not possible, at present, to specify that property of a coke on which the attainment of high temperatures of combustion depends. Apparently the harder cokes yield the higher temperatures, whilst the size of the coke pieces is of importance. There is evidence that the screening of coke, at the oven plant and at the blast furnaces, to remove pieces of less size than the minimum useful size (tentatively assumed to be 1½ in.), improves its behaviour on combustion in the blast furnace. From this point of view also, the production of hard cokes that resist fracture, with consequent less breeze formation, is desirable.

Size. The amount of breeze in the coke as delivered at the blast furnaces should be small. It is not always easy to estimate its amount. The best means of ensuring that the amount of breeze should be small would appear to be to encourage the production of hard cokes. When the minimum useful size of coke for blast-furnace practice has been determined, it may be found desirable to screen the coke at the blast furnaces as well as at the ovens to eliminate the smaller sizes.

From this survey of the more obvious chemical and physical properties of cokes it is evident that the most important are: Moisture- and ash-contents, hardness and size. The value of a coke for blast-furnace use can be improved by decreasing the amounts of moisture and ash it contains, by increasing the hardness and by eliminating breeze.

PART II

THE MANUFACTURE OF BLAST-FURNACE COKE TO SPECIFICATION

CHAPTER I

THE INFLUENCE OF THE CHARACTER OF THE COAL

The character of the coal used for coking has, of all the factors involved in the process, the greatest influence on the character of the coke produced. Its influence is difficult to define. The mechanism of coke-formation is but little understood and divergent views are held by different investigators. It is difficult to reproduce in the laboratory the conditions that obtain in coke-making practice, and erroneous conclusions are liable to be drawn from the results of laboratory tests far removed in their character from that of large-scale operations. It is essential, therefore, that any laboratory test of the " coking quality " of a coal should be standardised by comparison with commercial practice, and that the terms used when describing the phenomenon of coking should be carefully defined.

Large lumps of all bituminous and anthracitic coals on being heated leave solid residues which are more or less coherent. These may be termed " lump cokes." The quality of the lump coke depends on the "rank" (or degree of coalification) of the coal. Anthracites yield non-porous products, fissured by the escape of gases. British bituminous coals of carbon-content ranging between about 90 and 80 per cent. yield lump cokes that are coherent, porous and more or less swollen, whilst if they contain less than about 80 per cent. of carbon the lump cokes are non-porous, much fissured and less coherent. (See *Fuel*, 1927, **6**, 217).

Crushed coal, through $\frac{1}{4}$-in., say, on being heated at a rate of between 1 and 3° C. per minute (about the limits of the average rate of heating in large-scale coke-oven practice) agglomerates and yields a massive, coherent product (" coke "), if its carbon-content lies between about 90 and 80 per cent. As the percentage of carbon in the coal increases above 90, as in the South Wales steam coals, the product becomes less massive and less coherent until with the anthracites the particles of coal retain their original size and shape. Similarly, as the percentage of carbon in the coal decreases below 80, the massiveness and degree of coherence of the carbonised product decrease.

Coke for blast-furnace use was originally made (in Shropshire, Warwickshire, South Wales and Scotland) from large lumps of coal of comparatively low carbon-content, but nowadays it is almost invariably made from crushed slack. The coke so made must be sufficiently massive and coherent to withstand transport and handling between the ovens and the blast-furnace without much breakage into pieces less than $1\frac{1}{2}$-in. in size. A " coking-coal " can be defined as one of which the fines (through $\frac{1}{4}$-in.) will yield a marketable coke in normal coke-oven practice; a " non-coking coal " as one of which the fines will not, in like circumstances, yield a residue sufficiently coherent and massive to be readily saleable for blast-furnace use.

Industrial usage is introduced into these definitions to emphasise the distinction between commercial practice and laboratory test conditions, where particles of coal less than $\frac{1}{120}$-in. in size may be used and the rate of heating may be 200° C. or more per minute. In relation to such laboratory tests, it is preferable to refer to " caking " and " non-caking " coals, a caking coal being one which yields, as in the crucible method of determining " volatile matter," a caked residue, sometimes referred to as a " coke button " to avoid confusion with the product of large-scale operations.

The " caking power " (sometimes termed the " agglutinating power ") of a coal can be expressed by the number of parts of weight of inert material, such as sand or electrode carbon, which one part by weight of the coal can bind together into a coherent mass under standard conditions of test. The " caking power " of a coal is not necessarily a measure of its " coking power," *i.e.*, its ability to yield a marketable coke in practice.

Before considering more closely the influence of the character of coal on the quality of coke, a brief outline must be given of our present knowledge of the constitution of coal.

The Constitution of Coal

Coal is a conglomerate rock of vegetable origin. The purely organic material, coal, is composed of carbon, oxygen, hydrogen, nitrogen and sulphur, with traces only of other elements, such as phosphorus and arsenic (which may or may not be part of the coal-substance proper). No coal is of a precise homogeneous composition. Variations in the proportions of the constituent elements, and in their modes of combination, account for the many varieties of coals.

In order that the different varieties of coals may be utilised most efficiently it is necessary to know, for each variety, not merely the proportions of the constituent elements, but their mode of combination, so that the true composition of the conglomerate can be gauged. Such knowledge has been hard to attain, and has but recently been forthcoming. In the past, therefore, in default of such knowledge, the utility of different coals has been judged mainly by some specific measurable quality that they possess, such, for example, as their calorific value or their contents of " volatile matter." No doubt the close dependence of such qualities on some fundamental property enables them to be used with some success to assess the value of a coal. For accurate classification, however, more reliance is placed on knowledge of the elementary composition of the coal, despite the fact that knowledge solely of the proportions in which the elements are present can give no clue to their mode of combination.

As examples of the value of knowledge of the ultimate analyses of coals, it has been found (Seyler, *Proc. S. Wales Inst. Eng.*, 1900,

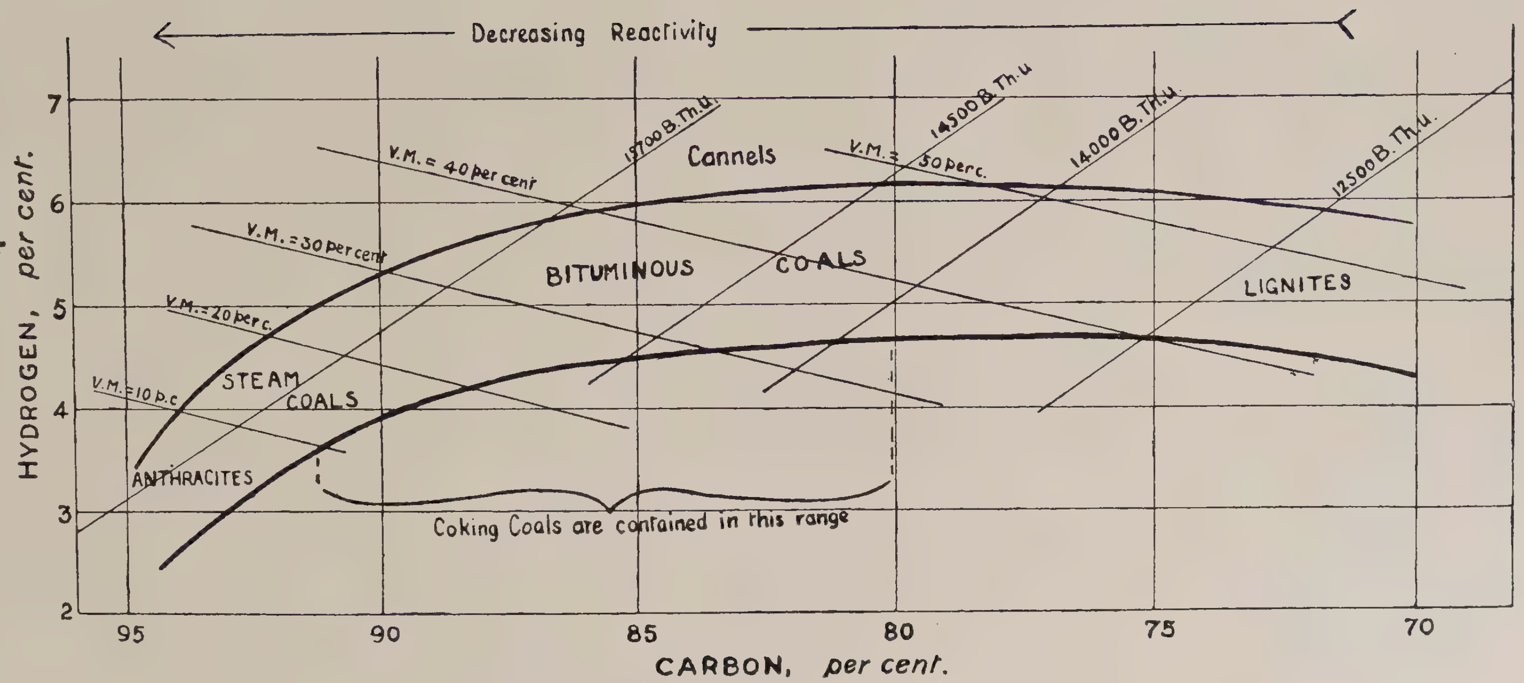


FIG. 43.—Coal-band (Carbon-content : Hydrogen-content).

Note.—Analyses on ash-free dry basis. The location of the band and contours is not precise.

21, 483; 1901, **22**, 112. *Fuel*, 1924, **3**, 15) that their general properties are dependent mainly on their carbon-contents, whilst, for a given carbon-content, the hydrogen-content determines other properties, such as the yield of " volatile matter " on heating (see Fig. 43). Coals with similar properties are not found at haphazard amongst a number having widely different compositions, but are grouped together by reason of similar ultimate analyses. Nevertheless, the correlation of the ultimate compositions of coals, from all sources, with their properties is far from complete, and, as far as it goes, is not as precise as could be desired. Reasons for this appear when the constitution of coal is studied more closely.

Coal.—The term *coal* is conveniently restricted in normal British usage to the black varieties of technical importance. Elsewhere, the term may be, and is, extended to include such fuels as lignites and brown coals, when the deposits are of such an extent and nature as to be of value commercially. Carbonaceous materials, such as peats at the one end of the scale of carbon-contents and graphites at the other, are not usually referred to as " coals." Nevertheless, by reason of the close relationship that exists between them, it is desirable to consider them in any discussion of the constitution of coal. The relationship between successive members of the series peats, brown coals, lignites, bituminous coals, anthracites and (perhaps) graphites has long been recognised. Each is derived from purely vegetable accumulations. Each covers a closely graded range of materials, and there is no sharp line of demarcation as between one member and the next.

From Peat to Anthracite.—There has thus naturally arisen a belief that the " coal " fuels form a continuous series in which the individual members differ one from another, not because of differences in the materials from which they were originally formed, nor even because of differences in their mode of formation, but because they represent successive stages in a slow process of " coalification." This " peat-to-anthracite " theory, or modifications of it, is now widely held, though it has been hotly debated in the past.

Microscopical Evidence. Evidence in support of the peat-to-anthracite theory is to be found in the readily demonstrable similarity of type amongst the materials from which the fuels were formed. Aside from such preferential accumulations of certain types of plant structures as characterise a few special coals, similarity in the structures and in their distribution has been demonstrated, for example, by Thiessen (U.S. Bureau of Mines, Bull. 117, 1920) as between the peats, brown coals, and bituminous coals of North America; and by Seyler (*Fuel*, 1923, **2**, 217) as between the bituminous coals and anthracites of Great Britain. The persistence of the same types of resistant plant-tissues, such as spore exines and cuticles, changed little by decay, is a feature common to all members of the series. Resins also, though not so resistant, have been shown (by David White (U.S. Geol. Survey, Prof. Paper 85, part E, 1914), for example) to persist in almost their original physical forms throughout the series up to, at least, the semi-anthracite coals.

Chemical Evidence. There is a similarity in the chemical nature of the materials of which each fuel is compounded. The noticeable differences in properties between successive members of the series can be related, chemically, to minor changes in the external groupings of the compounds present. The internal structures of the molecules, whether the compounds are contained in a peat or an anthracite, appear to be much the same.

Analytical Evidence. Perhaps the most striking evidence of the continuity of the " coal " series is to be found in analytical data, such as have been adduced by Seyler (*Fuel*, 1924, **3**, 15), Ralston (U.S. Bureau of Mines, Tech. Paper 93, 1915), Drakeley (*Trans. Chem. Soc.*, 1922, **121**, 221), and, more recently, by Hickling (*Trans. Inst. Min. Eng.*, 1927, **72**, 261), in a noteworthy paper to which reference should be made.

In conformity with the practice of the earlier investigators, Hickling has plotted, on rectangular co-ordinates, the elementary compositions of a large number of coals, and has shown that they occupy a narrow and continuous band over the whole range. The proportions of nitrogen and of sulphur appear to be constant throughout the range, varying but little from 1·5 and 1·0 per cent. respectively. The proportion of hydrogen in the coals (excluding the cannels and the anthracites of highest carbon-contents) varies between 4·5 and 5·5 per cent., that is to say, by only 10 per cent.; on the mean value 5·0 per cent. The main variation in composition falls, therefore, on the carbon and the oxygen, and the variations in these two elements are nearly complementary. The carbon varies between 50 per cent. in the peats and 95 per cent. in the anthracites. Of this total variation of 45 per cent., 17 per cent. covers the groups of bituminous coals and anthracites.

The approximate constancy of the proportions of nitrogen, sulphur, and hydrogen is expressed by the narrowness of the band when the carbon-contents are plotted against the oxygen-contents of the coals (see Fig. 44). That the band should be narrow during the early (low-carbon) stages is an indication that the hydrogen-content of the original coal-forming materials did not vary much from a mean value. That the band should remain narrow up to the high-carbon end of the range is evidence that similar changes have operated in the formation of all the coals, for any marked variation in the character of the coalification would have resulted in products of markedly different hydrogen-content for a given carbon-content.

Thus, at any period during the coalification process, the changes appear to be of definite and unvarying character, dependent on the nature of the material, and not on the immediate conditions to which it is subjected. No doubt the immediate conditions would affect the rapidity of the changes.

A consideration of the distribution curve of coal analyses leads to a further suggestion. The curve, with carbon and oxygen percentages as axes, is at the outset nearly straight. This suggests the gradual progress of but one kind of change. Assuming that the only kind of change, affecting ultimate composition, that can take place during progressive coalification is one involving loss of material, Hickling shows that the straight part of the distribution curve conforms with a gradual loss of carbon dioxide and water. The first straight portion of the curve ends at about 83 per cent. carbon, giving place gradually to a second straight portion over the range of 89 to 95 per cent. carbon. This range covers but a slight loss of oxygen, with a proportionately higher loss of hydrogen, perhaps as methane. There appears to be a scarcity of coals of about 86 per cent. carbon-content (*i.e.*, at the juncture of the two straight portions of the distribution curve), otherwise the distribution over the whole range is remarkably uniform.

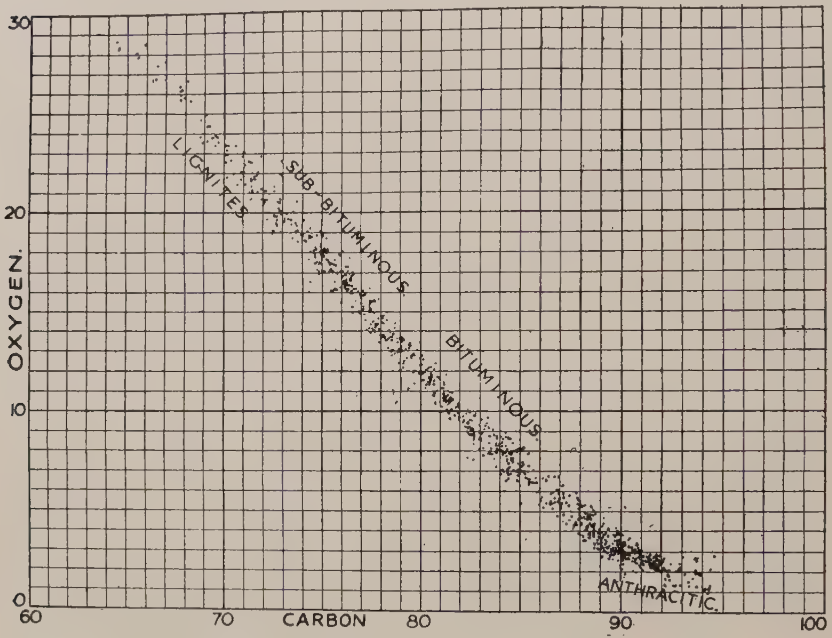


Fig. 44.—Coal Band (Carbon-content : Oxygen-content).

(Reproduced from Hickling, *Trans. Inst. Min. Eng.*, 1927, **72**, 261.)

The Formation of Coal.—The validity of the peat-to-anthracite theory is not universally admitted. It is maintained, for example, by some geologists that the process by which any given coal has been formed has not necessarily been slow and gradual. If this is so, it follows that each class, or each individual, in the series has been the outcome of individual coal-forming conditions. For example, Strahan and Pollard (*Mem. Geol. Survey, England and Wales*, 1915) have suggested that the partial anthracitisation of the South Wales coalfield is due to differences in the nature of the deposited plant materials, a suggestion which has little to support it. Donath (*Brennst. Chem.*, 1922, **3**, 231) has long maintained the view that for the formation of a bituminous coal a high temperature, involving partial distillation, is essential. A more moderate view, for which Erdmann (*Brennst. Chem.*, 1924, **5**, 177) has made out a plausible (but by no means flawless) case, is that, whilst brown coals have resulted from coalification at normal temperatures, a temperature of at least 300° C. is required for the formation of a bituminous coal. Both these suggestions fail to account for the regular distribution of coals over the wide range of carbon-contents. It seems probable that, whilst a moderate increase of temperature can be regarded as one factor in the process of coalification, it would influence rather the rapidity of the process than its end-point.

A new theory of coal-formation, definitely opposed to the peat-to-anthracite theory, has recently been put forward by McKenzie Taylor (*Fuel*, 1928, **7**, 203), based on the following novel observations. Beneath an impervious alkaline layer, such as is formed by the hydrolysis of sodium alumino-silica soils, resulting from base-exchange, bacterial decomposition of vegetable debris proceeds rapidly and to completion, mainly with the elimination of oxygen. This is due chiefly to the maintenance of mildly alkaline conditions, the acid products first formed, which would otherwise bring the decomposition to a premature close, being continuously neutralised.

Whilst most peats are formed under aerobic conditions, the accumulation of acid products limiting the extent of the decay, examination of the roofs of bituminous coal and anthracite seams shows that they have, in general, an alkaline reaction, and that the coals have been formed under alkaline anaerobic conditions. This differentiates them from the lignites and brown coals, for an examination of the roofs of their seams shows that they have not been formed under anaerobic conditions and that they may have undergone incomplete bacterial decomposition and partial oxidation.

McKenzie Taylor's view of coal formation, therefore, is that the vegetable material has first undergone a peat-like decay, under aerobic, acidic conditions. The duration of the extent of this "peatification" determines the nature of the product. If the decay is checked, as under a normal acidic or neutral cover, the peat deposit may ultimately form a lignite, but it can never become a bituminous coal. On the other hand, if the material in its particular state of arrested peat-decay is maintained under alkaline, anaerobic conditions, *e.g.*, under a cover of alkaline soils, a secondary decomposition will ensue. This, the "coalification" process proper, is rapidly carried to completion, the end-product being a coal the nature of which depends not at all on the geological conditions, nor on time, temperature and pressure, but solely on the degree of "peatification" before "coalification" began, each class of coal, sub-bituminous, bituminous or anthracitic, being a definite end-product.

This view, whilst differing fundamentally from the peat-to-anthracite theory, where each coal is regarded as an intermediate product leading progressively to the anthracites of high carbon-content, yet accepts and attempts to explain the gradual transition in composition observable throughout the range. It is early to judge as to the ability of McKenzie Taylor's theory to explain the apparently restricted and uniform distribution of coal compositions, for more data are required, but of the importance of the theory there should be no question. The discovery of the part played by a cover of alkaline soil in determining the extent of bacterial decay of vegetable debris provides a solution to the hitherto puzzling differences observed in the degree of preservation of particular plant entities, both in peat and in coal. The pronouncement that bituminous coals have of necessity been formed under an alkaline cover demands close consideration.

To sum up, whatever may be the agencies which have advanced or limited the degree of " coalification," there can be no doubt but that the different members of the series, peat-to-anthracite, represent the effects of increasingly prolonged or increasingly severe conditions on materials generally similar.

The Coal-forming Materials.—The nature of the changes that have taken place during coal formation can be followed roughly from the changes in composition of the coal-forming materials. Thus, as Hickling has pointed out, the transition from the original materials to lignites has involved a proportionate loss of hydrogen, probably as methane; the bituminous coals differ from the lignites as their carbon-content increases in that they have suffered an increasingly greater loss of carbon dioxide and water; whilst to form the anthracites, elimination of hydrogen, perhaps as methane, has again occurred. More precisely, the nature of the changes can be deduced from a study of the behaviour of different plant entities under the coal-forming agencies.

The original plant materials, though botanically of widely varied source and form, were, from a chemical standpoint, not so diverse. For all varieties of plants are built up of materials of but few general types. The physical forms and the relative proportions of the few types may vary widely, but the chemical nature of each remains substantially the same.

Wide differences in the relative proportions of the main types of original plant materials might be expected to result in coals having different properties. Different properties of the coals might also be expected should there have been differences in the agencies at work, either during deposition or during decay, tending to eliminate some of the original types of plant materials and thus to give prominence to others. In each coal, in fact, there must be present, in varied proportions, compounds, each of its own particular composition, derived from each type of plant material. The elementary composition of the conglomerate must thus depend in a complicated manner on the proportions and individual compositions of each contributant. At first sight, therefore, knowledge of the elementary composition of a coal would not seem to offer much guide to its true nature. When, however, we study in detail the contribution to "coal" made by each type of plant materials, it becomes evident that their original complexity has not survived. It is found that there are in bituminous coals but three or four groups of compounds of markedly different character, namely, resins and hydrocarbons (waxes), the protective tissues of the plants that have resisted decay, and a readily oxidisable material that forms the bulk of the coal. This simplification of the plant materials is already evident in peat, and thus presumably takes place during the early stages of decay.

Resins and Waxes. These normally form but a small part of the original plant material. Nevertheless, because of their resistance to bacterial decay and chemical change, they may bulk comparatively largely in the coal-forming material as other parts of it disappear through complete decay.

Protective Tissues. The waterproof protective coverings of plants, such as spore exines and the cuticles of stems and leaves, contain fatty substances which render them remarkably resistant to the processes of decay. These tissues, therefore, tend to accumulate in the coal-forming mass

Cellulose and Lignin. These compose the cellular framework of the plants and originally form their greatest bulk. During bacterial decay, much of the cellulose disappears. The remainder of the cellulose, and most of the lignin, together with the carbohydrates and proteins of the cell-contents, ultimately form complex brown products, soluble in alkali, which can conveniently be classed under the term "ulmin compounds." Each of the different cell-forming materials appears to be capable independently, under suitable conditions, of forming "ulmin compounds"; whilst such compounds are readily formed by interaction between carbohydrates and nitrogenous compounds derived from the proteins. Although the ulmin compounds can be derived from such different materials, the separation of them into groups having markedly different characteristics has not been found possible, and it would seem that the process of "ulmification" reduces all the materials that form the plant-cells to a common level. Since these materials form the bulk of the plants, the resultant ulmin compounds, despite wastage during decay, constitute the bulk of the decayed mass from which the coal is ultimately formed.

The Chemistry of Bituminous Coal.—*Soluble Constituents.* By the extraction of a bituminous coal with suitable organic solvents, it is possible to dissolve parts of it. The extracts so obtained include hydrocarbons and materials resembling natural resins in composition and properties.

The hydrocarbons consist of complex saturated (paraffin and naphthene) and unsaturated liquid hydrocarbons, with smaller quantities of solid paraffins and higher aromatic hydrocarbons. Their amount varies between about 0·5 and 3 per cent. of the coal. So far no relationship has been found between their quantity or composition and the composition of the coal from which they are obtained. They are mainly derived, presumably, from the fatty oils and waxes of the original plants, whilst the smaller amounts of free hydrocarbons associated with the plant cuticles are no doubt included. None of the fatty oils and waxes has survived as such in bituminous coals, but waxes are often prominent in brown coals.

The resins extractable by solvents are similar in character to resin inclusions which can sometimes be separated from bituminous coals by hand. They are often less changed, as compared with present-day resins, than are some fossil resins. Their amount varies normally between 0·5 and 3 per cent. of the coal, but occasionally considerably more may be present. Fig. 1, Plate XXVII illustrates inclusions of resins in a bituminous coal.

Both hydrocarbons and resins, after separation from bituminous coal, distil almost unchanged on heating. It is also possible, by carefully regulated heating, to separate both these classes of compounds direct from bituminous coal by distillation alone.

Resistant Plant Tissues. Organic solvents leave untouched the spore exines (see Fig. 2, Plate XXVII) and cuticles (see Fig. 3, Plate XXVII) which abound in the majority of bituminous coals and form the most prominent objects to be seen under the microscope. Their presence is most readily shown, and their amount estimated, by careful oxidation of the coal as a whole, whereby the main bulk of it becomes soluble in alkaline solutions. The insoluble residue consists largely of spore exines and cuticles, with some resistant woody cell structures (see Fig. 4, Plate XXVII). The amount of this residue varies considerably, a bright coal (*e.g.* a vitrain) perhaps yielding none, and a dull coal (a durain) as much as 20 per cent. by weight.

The spore exines and cuticles so separated from bituminous coal differ but little from the corresponding plant structures of to-day. Both spore exines and cuticles from coal are characterised by extreme resistance to decay and oxidation, and by the high proportion of tar which they yield on destructive distillation.

Ulmin Compounds. The bulk of the, normally, insoluble portions of bituminous coals can be so changed by carefully regulated oxidation as to become completely soluble in alkaline solutions. The materials recovered from the alkaline solutions are dark brown colloids, similar in many respects to the peat ulmins, but differing from them in that their carbon-contents are higher, and they are more definitely acidic. They are oxidation products of the coal ulmins, analogues of the peat ulmins.

The chlorination of bituminous coal also yields compounds which can be related to similar chlorination compounds obtained from the peat ulmins. In fact, throughout the series, peat, brown coals, lignites, and bituminous coals of increasing carbon-contents, chlorination yields, though with increasing difficulty, a graduation of compounds of similar characteristics. A study of the products of destructive distillation of each of the members of this series also reveals

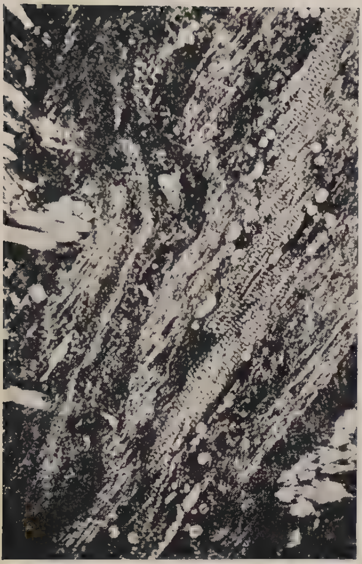


Fig. 1.—Etched surface of Hamstead vitrain, showing resin *in situ* in woody cell structure (× 130).

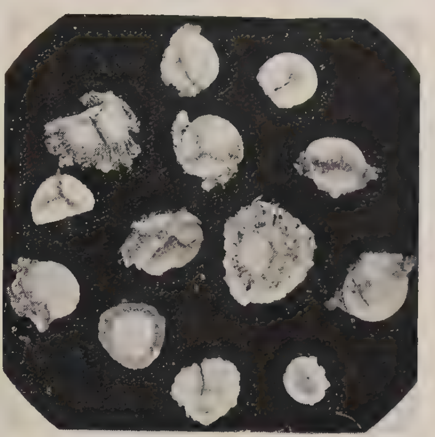


Fig. 2.—Megaspores isolated from Barnsley Seam (× 6).

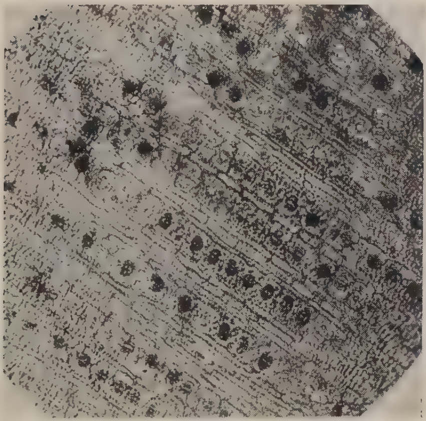


Fig. 3.—Cuticle showing cell impress and stomata (× 70).

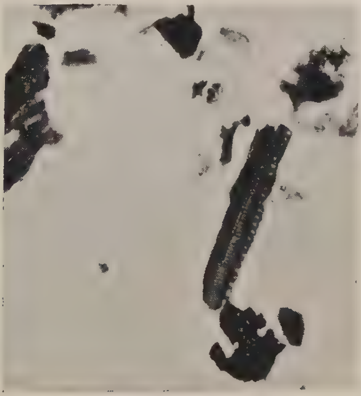


Fig. 4.—Woody tracheid showing scalariform pitting (× 140).

Plate XXVII.—Plant Entities Isolated from Bituminous Coal.

[*To face p.* 162.

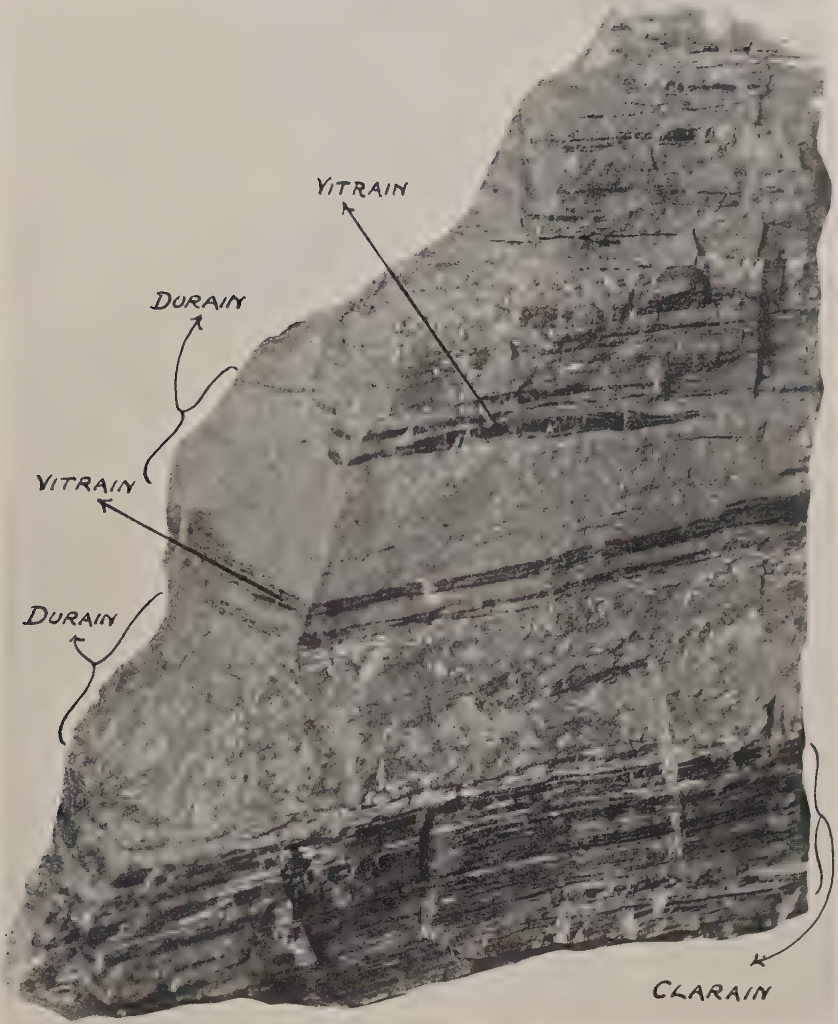

VITRAIN
DURAIN
VITRAIN
DURAIN
CLARAIN

Plate XXVIII.—Block of Bituminous Coal, Barnsley Seam, showing Banding.

[*To face p.* 162.

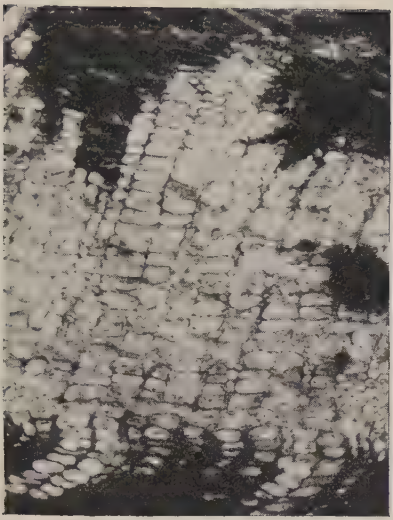


FIG. 1.—Vitrain, showing cell structure (vertical section) at high magnification (× 350).

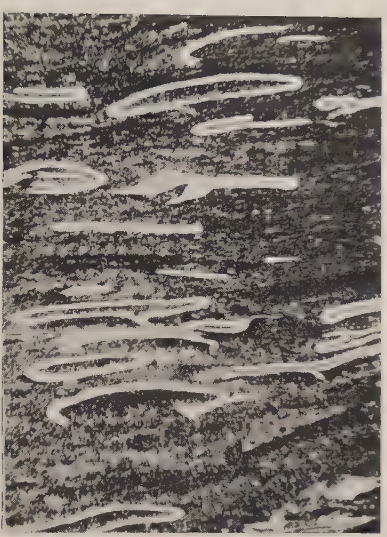


FIG. 2.—Durain, showing megaspore and microspore exines. Transparent vertical section (Silkstone Seam) (× 25).

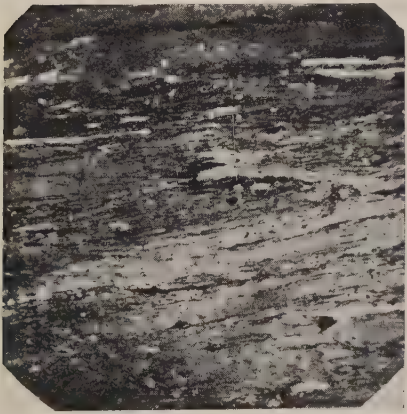


FIG. 3.—Clarain, transparent vertical section (× 90).

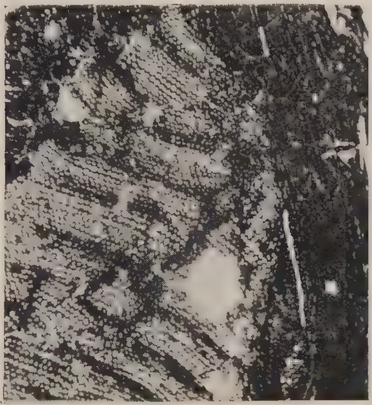


FIG. 4.—Fusain, showing woody cells. Thin vertical section (× 25).

PLATE XXIX.—Microscopic Structure of Ingredients of Banded Bituminous Coal.

[*To face p.* 162.

progressive differences in the character of the ulmin compounds that they contain.

This progressive relationship between the ulmin compounds in the different fuels, of which they usually form the major part, points to a progressive elimination of external groupings during coalification as the carbon-content of the fuel increases, such, for example, as would account for the progressive loss of carbon dioxide and water estimated from ultimate analyses by Hickling. As the carbon-content of the fuel increases, the ulmin compounds it contains become progressively more resistant to attack, whether by heat or by reagents. The increasing resistance to oxidation in particular affords a convenient measure of the degree of coalification of the ulmins. Such a measure is required when attempting a " rational " analysis of coal, for a complete specification of the quality of a coal must give expression to the degree of coalification of the ulmins as well as record their proportions and the proportions of hydrocarbons, resins and resistant plant entities that the coal contains.

Banded Bituminous Coal.—Whilst the effect of an increasing degree of coalification of the ulmins becomes apparent when comparing a number of coals of increasing carbon-contents, the extent to which differences in the relative amounts of the several ingredients of the conglomerate can affect the composition of a coal is well exemplified by a study of the macroscopic components, vitrain, clarain, durain, and fusain, of any given banded bituminous coal (see Plate XXVIII). The vitrain of a banded bituminous coal consists essentially of ulmin materials derived from the cellular structures of the plants (see Fig. 1, Plate XXIX). The durain is formed from mixed plant debris rich in resistant protective tissues, with a ground mass of ulmins similar, chemically, to those of the vitrain (see Fig. 2, Plate XXIX). The clarain is intermediate in character between the vitrain and the durain (see Fig. 3, Plate XXIX); whilst the fusain represents cell structures which have resisted bacterial decay, probably owing to early aerial decay, and now appear as opaque carbonised fibres (see Fig. 4, Plate XXIX). The chemical differences between these components of a banded bituminous coal have been shown to be caused solely by differences in the proportions in which the several ingredients are mixed together in each, the ulmin compounds being of the same composition and character throughout the whole coal.

The Classification of Coals.—To express the composition and quality of a coal fully it is necessary to specify the proportions of (1) hydrocarbons, (2) resins, (3) resistant plant entities, and (4) ulmin compounds that it contains, and to indicate the degree of coalification of the ulmin compounds. Analytical methods have been devised for obtaining this information.

It is reasonable to assume that, in general, the properties of a coal will be the sum of the properties of its ingredients. From our present knowledge we can relate, broadly, certain properties of coal with the properties and proportions of one or other of their main ingredients. We can, for example, relate their yields of tar on distillation at a given temperature, with their contents of hydrocarbons, resins and plant entities, and the character of the tar with the relative proportions of each. The reactivity of a coal towards reagents, such as oxygen, depends mainly on the degree of coalification of the ulmin compounds. The caking-power appears to be dependent to a certain extent upon the nature and amount of each of the ingredients and on their reactions one with another during destructive distillation, but there is evidence that the quantity of hydrocarbons and resins and the quality of the ulmin compounds (*i.e.* their degree of coalification) are of prime importance.

Elementary composition follows rational composition quite closely, since the latter is expressed mainly by the proportions of the minor ingredients and by the degree of coalification of the major ingredient, the ulmins. The degree of coalification of its ulmins greatly affects the elementary composition of a coal, in fact the carbon-content of a coal gives a rough measure of the degree of coalification of the ulmins it contains. On the other hand, variations in the amounts of the minor ingredients, which do not differ in elementary composition to a disproportionate degree from the rest of the coal, rarely effect more than slightly the ultimate analysis of the coal as a whole. For coals of the same type, therefore, ultimate analysis may be a satisfactory measure of the quality of a coal. For coals of varied types, however, it demands considerable judgment in its use.

ULTIMATE ANALYSES OF COALS

In South Wales, the coking coals are of high rank and contain between 90 and 87 per cent. of carbon (on an ash-free dry basis). In Durham, the carbon content of the coking coals lies between 89 and 85 per cent., in Yorkshire, it lies between 87 and 82 per cent., in Derbyshire, between 84 and 80 per cent., the Yorkshire and Derbyshire coking coals being of lower rank. These carbon-contents may be compared (Table LI) with the shatter indices of cokes made in the different districts to show, roughly, how the rank of a coal affects the quality of the coke made from it.

TABLE LI.—A COMPARISON OF THE RANK OF A COAL WITH THE QUALITY OF ITS COKE.

District.	Carbon-content of Coal (per cent., ash-free, dry.)	Vol. Matter of Coal (less moisture) (per cent.)	Shatter Index of Coke (1½-in. screen).
South Wales	90 to 87	18 to 25	over 95
Durham	89 to 85	25 to 30	95 to 85
Yorkshire	87 to 82	30 to 35	85 to 75
Derbyshire	84 to 80	35 or more	75 to 65

As a rough rule for British coals, it may be said that the higher the carbon-content of a coal, and the lower its amount of "volatile matter," the better the quality of the coke produced from it. Small differences in the amounts of volatile matter are insignificant, the total amount that a coal can yield on heating being of less moment than the amount it yields after the initial coke structure has become rigid.

Examples of ultimate analyses of coking coals from South Wales, Durham, Yorkshire and Derbyshire are given in Table LII.

TABLE LII.—ANALYSES OF COALS USED FOR COKING IN DIFFERENT DISTRICTS.

District and Seam.	C.	H.	O.	Moisture. Air-dried.	Volatile Matter. Dry, Ash-free.
	Dry, Ash-free.				
1. *South Wales.*					
No. 2 Rhondda	88·8	4·3	4·2	0·6	20·1
Two Foot Nine	89·4	4·6	3·5	0·4	23·5
Taff Rhondda	88·3	4·8	5·0	0·6	29·0
Blaenmawr	89·6	4·6	2·5	0·8	20·0
Cribbwr Fawr	87·9	4·8	5·0	1·1	29·0
Newlands	87·8	4·7	5·5	0·9	28·5
2. *Durham.*					
Low Main	86·8	5·2	5·5	0·6	32·1
Hutton	86·3	4·9	6·7	0·4	30·0
Beaumont	86·4	5·0	6·1	2·1	30·1
Busty	87·4	4·7	5·9	0·6	27·7
Brockwell	88·0	5·0	5·1	0·6	29·5
3. *South Yorkshire.*					
Wath Wood (Meltonfield)	82·7	5·4	8·9	2·5	34·5
High Hazel (Kent Thick)	83·8	5·2	8·0	1·7	36·3
Barnsley	83·7	5·1	8·7	2·0	35·2
Swallow Wood (Haigh Moor)	83·5	5·4	8·1	2·7	37·1
Lidgett	84·2	5·6	7·2	1·2	38·3
Flockton	82·2	5·5	9·3	1·9	38·7
Fenton	83·0	5·5	8·5	2·4	39·6
Parkgate	84·8	5·3	6·9	1·0	37·0
Silkstone	86·0	5·4	6·1	0·8	35·3
Halifax Soft	86·1	5·3	6·8	0·9	33·5
4. *Derbyshire.*					
Waterloo	80·1	5·3	11·6	5·5	38·4
Deep Soft	81·2	5·4	9·5	4·7	37·5
Deep Hard	82·4	5·3	8·8	3·5	37·6
Tupton	82·1	5·2	9·0	3·5	36·8
Black Shale	82·6	5·2	7·8	2·9	38·1

In the examples from the Durham, Yorkshire, and Derbyshire coal-fields the coals have been listed in the order in which the seams occur below the surface. The samples from Derbyshire were all obtained at the same colliery, but the samples from the other districts were taken from different collieries. The composition of a seam varies from place to place, so that the analysis given for any particular seam should not be regarded as a rigid analysis for that seam.

The Welsh coking coals are of high carbon-content and low hydrogen- and oxygen-contents. It is usual in South Wales to coke a mixture of a bituminous with a " low volatile " steam coal, the amount of volatile matter in the mixture being about 22 per cent. The Durham coking coals are of high carbon-, fairly low hydrogen- and low oxygen-contents. The amount of volatile matter is fairly low. The Yorkshire coking coals are of lower rank. Their hydrogen contents are high. With Durham coking coals it is unusual for the hydrogen to exceed 5 per cent., but Yorkshire coking coals, even though of high carbon-content, almost invariably contain over 5 per cent. of hydrogen. The amount of volatile matter is, in consequence, usually high. The oxygen-content is generally higher than in Durham coking coals. Derbyshire coking coals are of still lower rank, low in carbon and high in hydrogen, oxygen, and volatile matter.

The coking coals in each district are in general similar to each other and distinct from those in another district, so that one can refer to a typical " Yorkshire " or a typical " Derbyshire " coking coal in the same way as to typical " Yorkshire " and " Derbyshire " cokes. In this connexion it may be remarked that the coke made from the Halifax Soft seam (and the Better Bed seam) in Yorkshire has the character more of a " Durham " than of a " Yorkshire " coke, just as the carbon-contents and volatile matter-contents of these seams are more nearly those of the " Durham " than of the " Yorkshire " coking coals.

A carbon-content for the coal of about 86 per cent. (on an ash-free dry basis) appears to be a critical point with respect to the quality of the coke, provided that both the hydrogen- and the volatile matter-contents are fairly low. If the carbon-content of the coal falls below 86 per cent., the coke is liable to contain large pores and to be much fissured and therefore weak.

Rational Analyses of Coals

The range of carbon-contents of coking coals is narrow. The oxygen-content, which might be expected to provide valuable information as to the coking properties of a coal, is unfortunately unreliable because it cannot, as yet, be determined directly. The rational analysis of a coal provides an index of its degree of coalification and the range of values for this index amongst coking coals is wide. We believe that, with experience in their use, rational analyses will prove of more value than ultimate analyses in enabling a judgment of the properties of coals to be formed. Rational analyses of a number of coals are recorded in Table LIII, together with their carbon-contents and indices representing the " mechanical strength " of the cokes made from the coals in full-scale oven tests.

This "mechanical strength" index is the product of the $1\frac{1}{2}$-in. shatter index and the $1\frac{1}{2}$-in. abrasion index divided by 100.

TABLE LIII.—COMPARISON OF RATIONAL ANALYSES OF COALS WITH THE QUALITY OF COKE PRODUCED.

Coal Seam.	Resins and Hydro-carbons (per cent.).	Plant Remains (per cent.).	Ulmins (per cent.).	Reactivity of Ulmins.	Carbon, per cent. in Coal. Dry, Ash-free.	Mechanical Strength Index of Oven Coke.
Two Foot Nine (S. Wales)	<1·0	22·6	76·4	25	89·4	95
Victoria (Durham)	0·7	22·7	76·6	28	89·1	93
Halifax Soft (S. Yorks.)	4·6	4·2	91·2	50	86·1	90
Busty (Durham)	2·5	5·2	92·3	34	88·2	87
Mountain Mine (Lancs.)	4·0	Trace	96·0	33	86·1	87
Parkgate R.M. (S. Yorks.)	4·4	2·4	93·2	64	84·8	86
No. 5 (Kent)	4·9	4·3	90·8	41	86·9	83
Parkgate A.M. (S. Yorks.)	3·7	5·9	90·4	49	84·2	79
Barnsley (S. Yorks.)	3·1	1·7	95·4	47	83·7	76
Swallow Wood (S. Yorks.)	4·2	9·3	86·5	64	81·8	70
Tupton (Derby.)	3·3	2·0	94·7	62	81·8	70
Silkstone (S. Yorks.)	3·8	13·3	82·9	22	86·0	68
Deep Soft (Derby.)	2·4	5·2	92·4	77	81·8	66
Black Shale (Derby.)	3·5	0·4	96·1	58	81·8	62
Waterloo (Derby.)	2·9	3·2	93·9	63	81·5	60
Deep Hard (Derby.)	2·8	12·2	85·0	72	82·3	54
Top Hard (Notts.)	2·8	3·1	94·1	62	81·6	Non-coking.
Thick (S. Staffs.)	3·1	6·9	90·1	75	79·9	
Main (Leicester.)	2·8	9·1	88·1	89	76·5	

The coals which yield the best cokes, as judged from their "mechanical strength" index, contain but little resins and hydrocarbons but are rich in organised plant remains (which give a high yield of oils on carbonisation). In the Busty coal, also, the amount of resins and hydrocarbons is low. With these exceptions, only the poorly-coking or non-coking coals of those listed in Table LIII contain a low proportion of resins and hydrocarbons. Other poorly-coking coals that we have examined, however, have contained higher proportions of resins and hydrocarbons.

The reactivity of the ulmins is low with the good coking coals and high with the poorly-coking and non-coking coals. It may be that the poor quality of the coke from coals having ulmins of high reactivity is due to an insufficiency of fusible constituents by which the highly reactive ulmin surfaces can be wetted during coke formation. The consideration of rational analyses of coals in relation to the problems of coke formation forms the subject of several researches now in progress in the Department of Fuel Technology of Sheffield University.

CAKING POWER

A comparison between the "caking power" and the "coking power" of coals has been made by Dr. L. Slater for the South Yorkshire Survey Committee of the Fuel Research Board in collaboration with this Committee (see L. Slater, "A Comparison of Methods for Testing the Caking Properties of Coals," Report of the Fuel Research Board for 1929, Appendix IV). Slater has reported the results obtained by four different methods of assessing the "caking power" ("agglutinating power") of a series of coals which we have used for the manufacture of cokes and has compared them with the 1½-in. shatter indices of the cokes. A summary of his results is given in Table LIV.

TABLE LIV.—COMPARISON BETWEEN VARIOUS CAKING INDICES OF COALS AND THE SHATTER INDICES OF THEIR COKES (SLATER).

Coal No.*	Carbon.	Volatile Matter.	Caking Index.				Shatter Index (1½-in.).
	Per cent., Ash-free Dry.		Campredon-Gray.	Barash.	Meurice.	Burdekin.	
S.W.1	91·4	19·4	14·5	9·5	64	55	97·2
S.W.2	89·5	21·9	13	10	40	60	96·5
D.1	87·8	27·6	19	15·5	236	—	91·1
Y.3	84·1	34·2	8	10	85	66	85·8
K.	88·0	30·1	16	17·5	237	—	85·6
C.1	85·8	36·8	11	17	60	—	84·6
D.6	86·2	26·8	14	16	122	85	83·9
Dy.2	82·8	37·2	11·5	9·5	57	16	83·0
Y.6	86·2	34·3	8	11	80	128	81·9
L.4	83·7	37·8	9	14·5	54	63	80·5
Y.5	85·0	35·7	9·5	14	118	140	80·1
Y.2	84·6	33·9	12	14	86	77	76·5
C.2	83·7	37·4	9·5	14	53	116	73·9
Y.9	83·5	37·9	10	13·5	70	89	72·5
Y.8	85·6	35·2	14	20	667	—	72·2
Dy.4	83·3	37·2	8	10·5	55	18	69·9
Dy.5	81·8	37·2	7	5·5	30	2·5	69·7
Dy.3	82·6	39·2	10·5	11·5	40	53	69·6
Y.10	83·7	36·8	11	13	57	125	66·1
Dy.1	84·5	38·3	17	15·5	135	81	65·0

* S.W. = South Wales. D. = Durham. Y. = Yorkshire. Dy. = Derbyshire. K. = Kent. L. = Lancashire. C. = Cumberland.

In the Campredon-Gray test (*Fuel*, 1923, **2**, 42), the caking index is given by the number of parts by weight of sand with which one part by weight of the coal can be mixed so that, when the mixture is carbonised during 7 min. in the platinum crucible test for "volatile matter," not more than 5 per cent. of loose powder is produced and the coke button will rest under a weight of 500 g. without crumbling. In the Barash test (*Fuel*, 1927, **6**, 532), the caking (agglutinating) index is the limiting number of parts by weight of electrode carbon with which one part by weight of the coal can be mixed so that an incoherent powder is obtained when the mixture is carbonised in a silica retort during 5 minutes at 800° C. In the Meurice test (*Ann. Mines. Belg.*, 1914, **19**, 625) 1 gram. of the coal mixed with 17 grams of sand is carbonised and the crushing strength of the coke button then determined, the caking index being the product of the weight of sand and the crushing load in kg., divided by the weight in grams of the loose powder produced. Burdekin's test (Physical and Chemical Survey of the National Coal Resources, Paper No. 8, 1927) involves the determination of the crushing strength of coke buttons made from samples of the coal admixed with different proportions of calcined anthracite and carbonised up to 860° C., the rate of rise of temperature being 3° C. per minute. The area enclosed by the " caking power curve " (constructed from the crushing loads of the different mixtures) and the axes of reference is regarded as the " caking index." In each of these tests, the sizes of the particles of coal and inert material used, and all details of operation, are standardised. The original papers should be consulted for the details.

The different coals are not placed in the same order of caking value by the different tests, and some of the best coking coals would be adjudged inferior by them. On comparing the caking indices and carbon-contents of the coals with the shatter indices of the cokes made from them, it appears that for coals of high carbon-content (*e.g.*, S.W.1 and S.W.2) the caking index (*e.g.*, by the Barash test) can be low but the coal can produce an excellent coke, whereas if the carbon-content is low (*e.g.*, Y.3, Dy.2) the coke is inferior even though the caking index may be the same. The relationship between the carbon-content of the coal and the shatter index of the coke, and between the carbon-content of the coal and its caking index is illustrated by Slater by two diagrams which are reproduced in Figs. 45 and 46. These diagrams show that the shatter index of the coke rises continuously with the carbon-content of the coal, whereas the caking index rises to a maximum at about 86 per cent. carbon and then falls. There cannot, therefore, be a simple relationship between the caking index of a coal, as determined by any of these laboratory tests, and the shatter index of the coke produced from it.

This defect of laboratory " caking indices " as at present devised requires to be emphasised, for many coals have been, and still are being, wrongly classed as " poorly coking " on the faulty evidence provided by a laboratory " caking index." It can be understood that a coal of low caking index might be of less value than one of high caking index for blending with a non-caking coal, such as some of the low-volatile Continental coals, for the manufacture of coke or gas. There is evidence, also, that a mixture of coals having different caking power may yield a coke of irregular quality unless carefully blended, a blend of low caking index tending to yield a coke that is readily abraded and produces a low combustion temperature on being burnt (see p. 136). It is possible that a high caking index may mean that a coal possesses properties that should

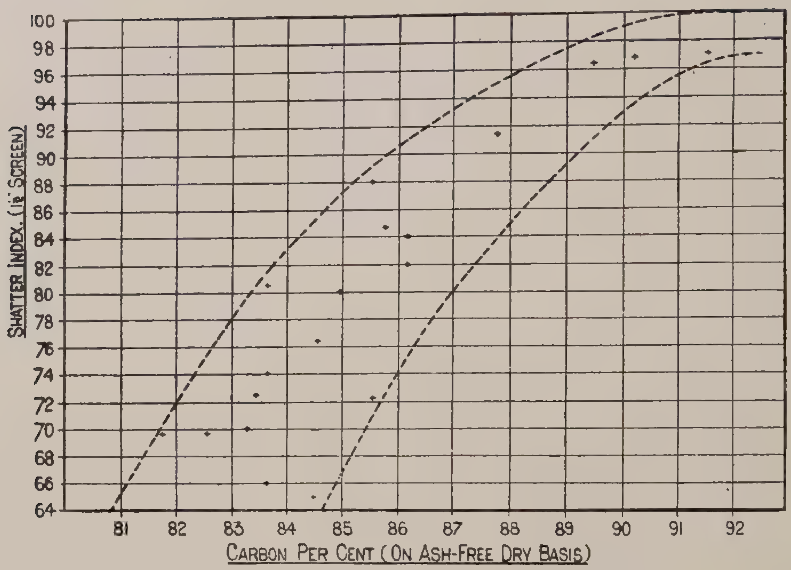


FIG. 45.—Comparison of Carbon-content of Coal with Shatter Index of Coke.

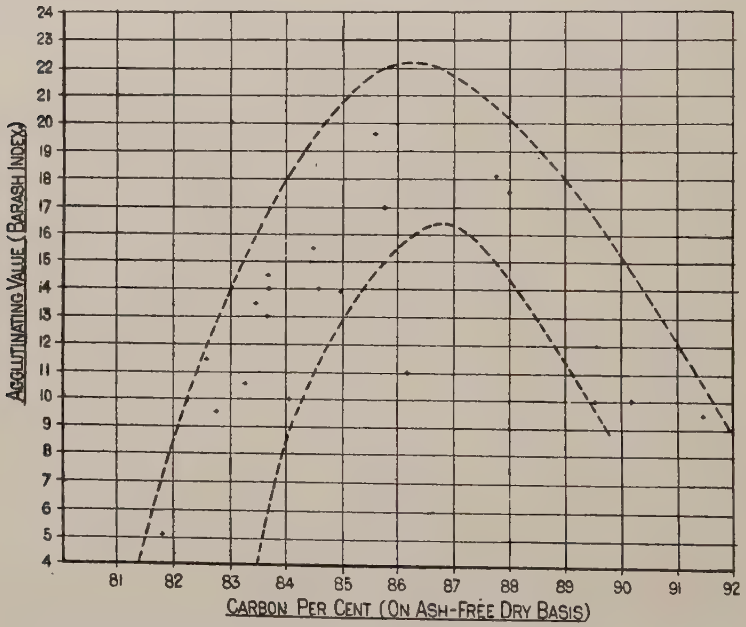


FIG. 46.—Comparison of Carbon-content of Coal with Agglutinating Value of Coal.

render it capable of yielding a coke of the highest quality provided that the conditions of carbonisation are correctly chosen.

Numerous laboratory tests have been devised for studying the phenomena of coke-formation, in the hope of being able to forecast the results of using different coals for coke-making in commercial practice. For example, Slater (*Fuel*, 1927, **6**, 82) has determined the " swelling power " of a number of coals when heated at different rates in the Gray-King assay apparatus, and has shown that there is a relationship between the swelling power and the coking value of many coals. Foxwell (*Fuel*, 1924, **3**, 122) has determined the temperature of initial and final plasticity of coals, and their resistance whilst plastic to the passage of gases, when they are raised in temperature at a specified rate. Audibert and Delmas (*Fuel*, 1927, **6**, 131) have determined the softening temperatures (" melting points ") of coals and their temperatures of expansion under standardised conditions of heating.

These methods have been carefully studied in our laboratories and a method which embodies some of the features of each, and give most of the information provided by them, has been evolved. Before describing this method, it is desirable to outline the various stages in the formation of coke, so far as they are known.

Stages in the Formation of Coke

When a single particle of coal is slowly heated in the absence of air (at, say, 1° C. per minute), it begins to expand at a certain temperature and the expansion continues, as the temperature is increased, up to a maximum. We have measured this expansion by heating in a reducing atmosphere 1-in. cubes of a number of coals to different temperatures in a muffle furnace. The results obtained for cubes of one coal (Parkgate, R.M.) are recorded in Table LV. The results are, usually, averages of two or three determinations.

Table LV.—Percentage Increase in Volume of Cubes of Parkgate R.M. Coal on Heating.

Temp. (° C.)	Increase in Volume (per cent.).	Oils Extractable by Ethyl Ether (per cent.).	Remarks.
15	Nil	0·05	
330	Nil	2·70	
340	Nil	1·90	
350	Nil	2·20	
360	100	2·50	Cracks in bedding plane had glistening surfaces.
370	50	2·60	
380	120	2·20	Most of the surface of the coal glistening.
390	60	1·90	
400	130	1·50	
410	110	2·30	
420	190	2·20	
430	340	0·40	

Some of the oil contained in the coal is released on heating at a low temperature but is not distilled until a higher temperature has been reached.

When a column of coal particles with a piston resting on it is heated at 1° C. per minute) in a vertical tube, a contraction of the (apparent) volume occupied by the coal occurs at a certain temperature and at a somewhat higher temperature there is an expansion This expansion continues as the temperature is raised, reaches a maximum which is maintained over a considerable temperature range, and is followed by a slight shrinkage. These changes in volume for columns of Parkgate R.M. coal are recorded in Table LVI.

TABLE LVI.—CHANGES IN VOLUME OF COLUMNS OF PARTICLES OF PARKGATE R.M. COAL ON HEATING.

Temp. (° C.).	Percentage Decrease or Increase in Volume.			Oils Extractable by Ethyl Ether (per cent.).
	Load on Column, 2 g.	Load on Column, 100 g.	Load on Column, 1000 g.	
330	Nil	Nil	Nil	—
340	Nil	Nil	— 0·5	—
350	Nil	— 0·2	— 3·0	3·6
360	Nil	— 1·5	— 6·2	—
370	— 0·2	— 4·4	—12·5	2·7
380	— 0·6	— 9·3	—17·0	3·9
390	— 3·1	— 15·0	—20·0	3·3
400	+ 72	+ 37	+10	—
410	+151	+128	+30	—
420	+214	+134	+30	6·4
430	+239	+134	+30	—
440	+239	+134	+30	—
450	+239	+134	+30	0·8

These changes in volume are shown graphically in Fig. 47, which also records " abrasion indices " for the products obtained at the different temperatures. For the abrasion test, the product was broken up into pieces of uniform size and rotated during 30 minutes in a cylinder 1 in. long and 1 in. in diameter at a speed of 20 r.p.m., thus reproducing, in miniature, a drum abrasion test. After this treatment, the product was screened and the proportion passing through a 60-mesh sieve was recorded as the " abrasion index." Since the coal used had originally all passed through a 60-mesh sieve, this test gave an indication of the degree of agglomeration of the particles.

At a temperature approximating the same as that at which the initial expansion of the single cube of the coal occurred, there was a contraction of the column. The space occupied by the coal particles in the column would be only about two-thirds of the apparent volume. The expansion of the individual particles is accompanied by the evolution of oil, some of which is retained by the coal. In a column of particles, there is not the same freedom for expansion, but some no doubt occurs and the oils distilled out of one particle with neighbouring particles, expelling the air or gases from their surfaces and causing, by surface tension effects, a contraction in volume. Since gases are being evolved from the decomposing coal, but cannot readily be released, they accumulate and tend to distend the whole mass. The pressure of the gases rises until it is sufficient to allow of their escape through the coal mass, which is distended during the process. There is another physical change in the column of coal during this period, for it is not merely a collection of rigid particles filmed with oil. Oil impregnates each particle, dispersing the infusible portion of the coal and rendering the particle plastic. As the temperature rises, some oil is distilled from the coal surfaces and some of the oil-films are decomposed.

The release of gases through the now porous mass forms a network of pores (mostly open). Finally, gas can be released from the mass without causing its further expansion. All the oils are at length distilled and the coke structure becomes rigid, suffering but little further change of form as the temperature rises. The loss of volatile matter from the rigid coke structure causes shrinkage and the formation of fissures.

The changes occurring in a column of coal particles heated in a tube, up to the moment when the coke structure becomes rigid, are illustrated on Plate XXX. The early changes in the coal mass continue over a range of temperatures (the contraction range), and the exact temperature of initial contraction depends considerably on the conditions of the test. If, for example, a piston resting on the column of coal is weighted so as more rapidly to decrease the free space between the particles during the test, a low " temperature of initial contraction " is observed. There is no definite softening-point, or melting-point, of the coal which a contraction in volume of the column of coal particles can disclose. The " temperature of initial expansion " is more definite, for it indicates, approximately, the filling up of the free space in the column by expansion of the individual coal particles.

As illustrated on Plate XXX and in Fig. 47, the " coke " formed below the temperature of initial expansion is non-porous, consisting of a collection of coal particles set in a cement of oils or of pitch resulting from the decomposition of the oils. A true coke is only formed after the temperature of initial expansion has been passed, when pores are produced and the forces of expansion have caused coalescence of the coal particles.

A certain degree of expansion is thus advantageous in causing homogeneity of the coke, but expansion to such an extent as to close all voids between the coal particles is not essential for the formation of coke. If the expansion of the coal is insufficient to close all the voids (about 33 per cent. of the charge in a coke oven), the coke formed is less homogeneous. If the maximum expansion of the coal is more than sufficient to close all the voids (*i.e.*, is more than about 33 per cent.), intimate contact, and coalescence, of the coal particles occurs at an earlier stage of the heating than it does

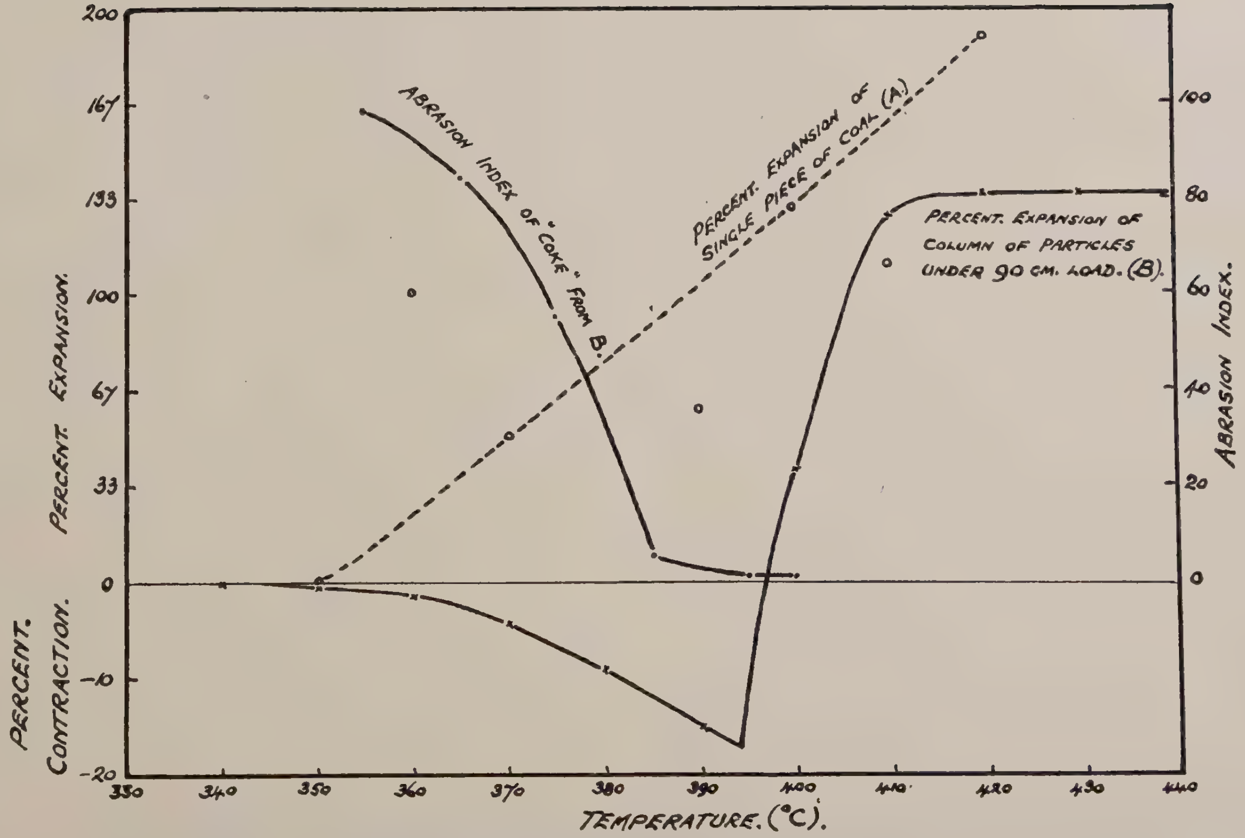
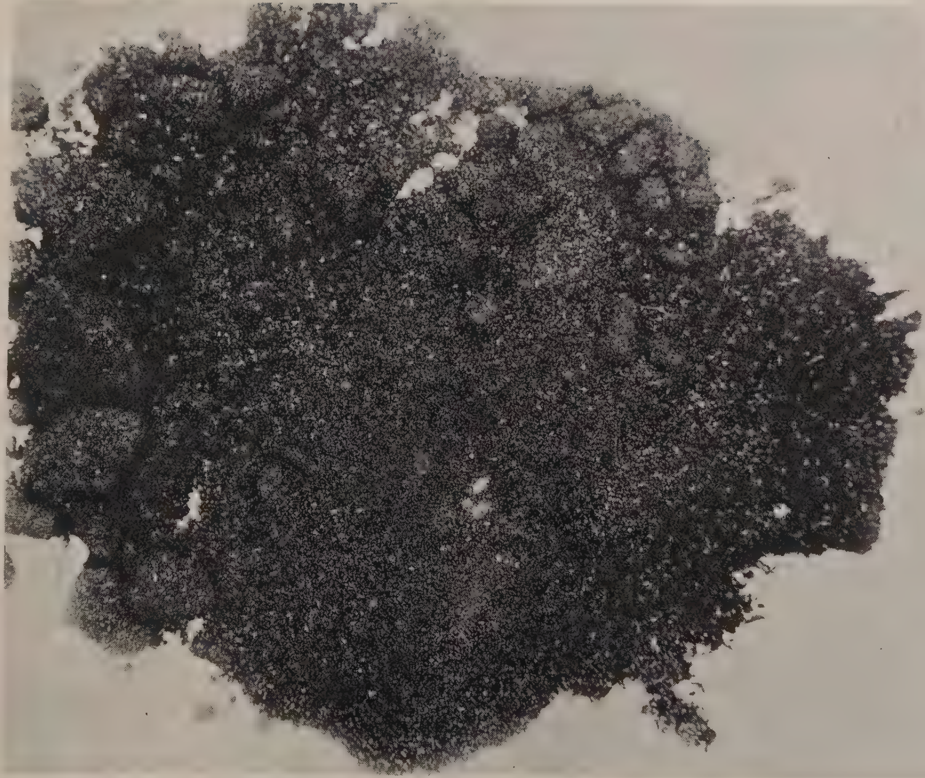
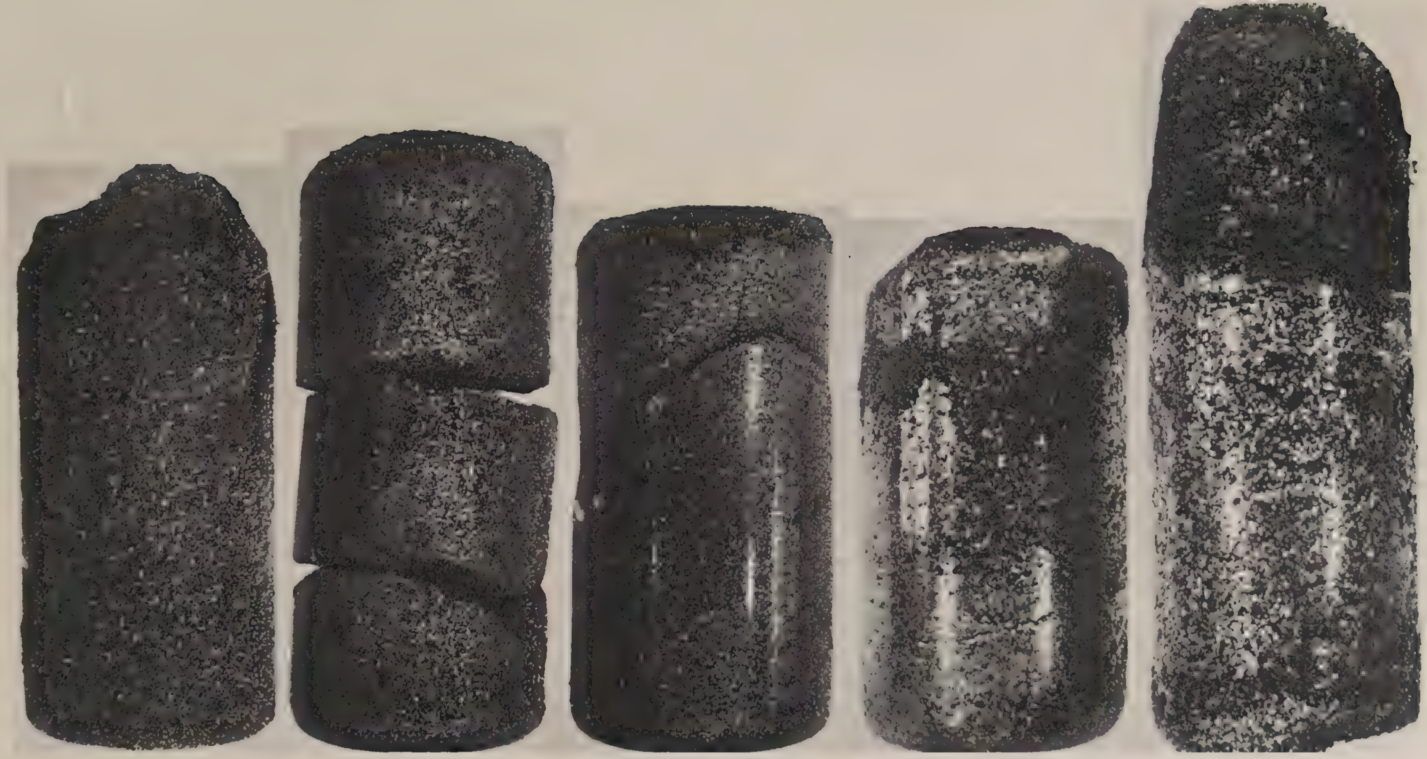


FIG. 47.—Per Cent. Alteration in Volume of Single Piece and of Column of Particles of Parkgate R.M. Coal. Heated to Different Temperatures. (Cf. Plate XXX.)



Temperature to which heated . .	325° C.	355° C.
" Abrasion Index "	100·0	99·0



Temperature to which heated . .	365° C.	375° C.	385° C.	395° C.	400° C.
" Abrasion Index " .	85·0	55·0	5·5	1·4	1·6

Plate XXX.—Stages in the Formation of Coke. Parkgate R.M. Coal (60-mesh) Heated to Different Temperatures in Vertical Tube under Load of 100 Grams. (Cf. Fig. 47.)

when the maximum expansion of the coal only just reaches about 33 per cent., and the coal remains plastic during a longer period. The coke then is, in consequence, more homogeneous.

There are thus several phases through which the coal charge in a coke oven must pass before a satisfactory coke structure can be formed, namely: (1) The release of the oils contained within the coal substance, so that they are less firmly incorporated with the coal than at atmospheric temperatures. (2) The discharge of part of these oils to the surfaces of the coal particles, which they wet (thereby displacing films of air and gas); and the dispersion of the infusible portions of the coal-substance by oils released within the mass of each particle, whereby each particle becomes plastic. (3) The expansion of the individual coal particles, accompanied by a general contraction of the mass of particles (due to the surface tension of the oil films) until all the voids in the mass are closed. (4) The expansion of the mass as a whole.

THE EXPANSION OF COAL

We have previously remarked that non-coking coals of high volatile matter (and high oxygen) content may contain no less an amount of resins and hydrocarbons than is present in coking coals. Their lack of coking quality is probably due to the inability of the oils they contain to wet the oxygenated surfaces of the coal particles. In the absence of such wetting, gases can escape from the coal mass without causing its expansion; and if the wetting is incomplete, the expansion may be insufficient to produce a homogeneous coke. It is probable, therefore, that the percentage maximum expansion of a coal under standardised conditions of heating can be related to its "coking power." Table LVII records the expansion for a number of coals as determined by a laboratory test.

In this test, all the values obtained are relative and dependent on the test conditions. The effects of variations in the test conditions will be recorded fully elsewhere. The conditions used for the determinations recorded in Table LVII were as follows: Six grams of the freshly-ground coal (through 60 mesh I.M.M. standard) were introduced into a silica tube of 16 mm. internal diameter so as to form a column 40 mm. long. The tube was heated in a vertical electric furnace at a rate of 1° C. per minute. A plunger, weighing 100 grams, rested on the top of the column of coal. The apparatus, which is an improved form of that described by Bradley and Mott (*Trans. Inst. Min. Eng.*, 1929, **76**, 200) is illustrated in Fig. 48.

The temperatures of initial contraction and the temperatures of initial and final expansion appear to bear no relationship to the carbon-contents of the coals or to the mechanical strength of the cokes made from them. The percentage expansions of the coals, however, conform fairly well with the quality of their cokes, a high value for the expansion denoting a high quality coke. There are four irregularities amongst the nineteen bright coals tested: Busty, Mountain Mine, Swallow Wood and Silkstone. If the broad con-

TABLE LVII.—THE CONTRACTION AND EXPANSION OF DIFFERENT COALS IN A LABORATORY COKING TEST.

Coal Seam.	Carbon Content of Coal. Dry, Ash-free.	Mechanical Strength Index of Oven Coke.	Temperature in ° C. of			Contraction.		Expansion.	
			Initial Contraction.	Initial Expansion.	Final Expansion.	Range (° C.).	Per cent.	Range (° C.).	Per cent.
Two Foot Nine (S. Wales)	89·4	95	383	429	450	46	17	21	145
Victoria (Durham)	89·1	93	365	414	434	49	27	20	134
Halifax Soft (S. Yorks.)	86·1	90	346	395	408	49	28	13	136
Busty (Durham)	88·2	87	362	407	430	45	24	23	199
Mountain Mine (Lancs.)	86·1	87	354	414	424	60	23	10	67
Parkgate R.M. (S. Yorks.)	84·8	86	342	395	412	53	19	17	129
No. 5 (Kent)	86·9	83	363	413	438	50	24	25	126
Parkgate A.M. (S. Yorks.)	84·2	79	357	397	409	40	15	12	119
Barnsley R.M. (S. Yorks.)	83·7	76	364	406	420	42	23	14	65
Swallow Wood (S. Yorks.)	81·8	71	364	—	413*	49	25	—	Nil
Tupton (Derby.)	81·8	70	362	413	427	65	20	14	13
Silkstone (S. Yorks.)	86·0	68	347	400	422	75	15	22	100
Deep Soft (Derby.)	81·8	66	351	406	428	55	23	22	19
Winter (W. Yorks.)	83·4	66	373	414	431	41	21	17	8
Black Shale (Derby.)	81·8	62	361	412	432	51	21	20	12
Barnsley H. (S. Yorks.)	82·7	60	350	—	420*	70	30	—	Nil
Waterloo (Derby.)	81·5	60	320	—	442*	122	25	—	Nil
Deep Hard (Derby.)	82·3	54	361	—	416*	55	25	—	Nil

* Final contraction.

clusion is drawn that a coal giving an expansion of 100 per cent. or more (under the test conditions) should yield a good coke, and one giving an expansion of 25 per cent. or less a poor coke, there are only two serious exceptions: Mountain Mine and Silkstone. The coke from the Mountain Mine coal differs in appearance from those made from coals of like carbon-content, being duller and seemingly imperfectly "fused." The contraction range and percentage contraction of the coal are both high. The Silkstone coal has behaved exceptionally in all laboratory tests, its "caking index" for example, being remarkably high. In the test under consideration, the percentage expansion is higher than would be expected from the quality of the coke it normally yields and the percentage contraction is low. It may well be that, given the optimum conditions of coking, yet to

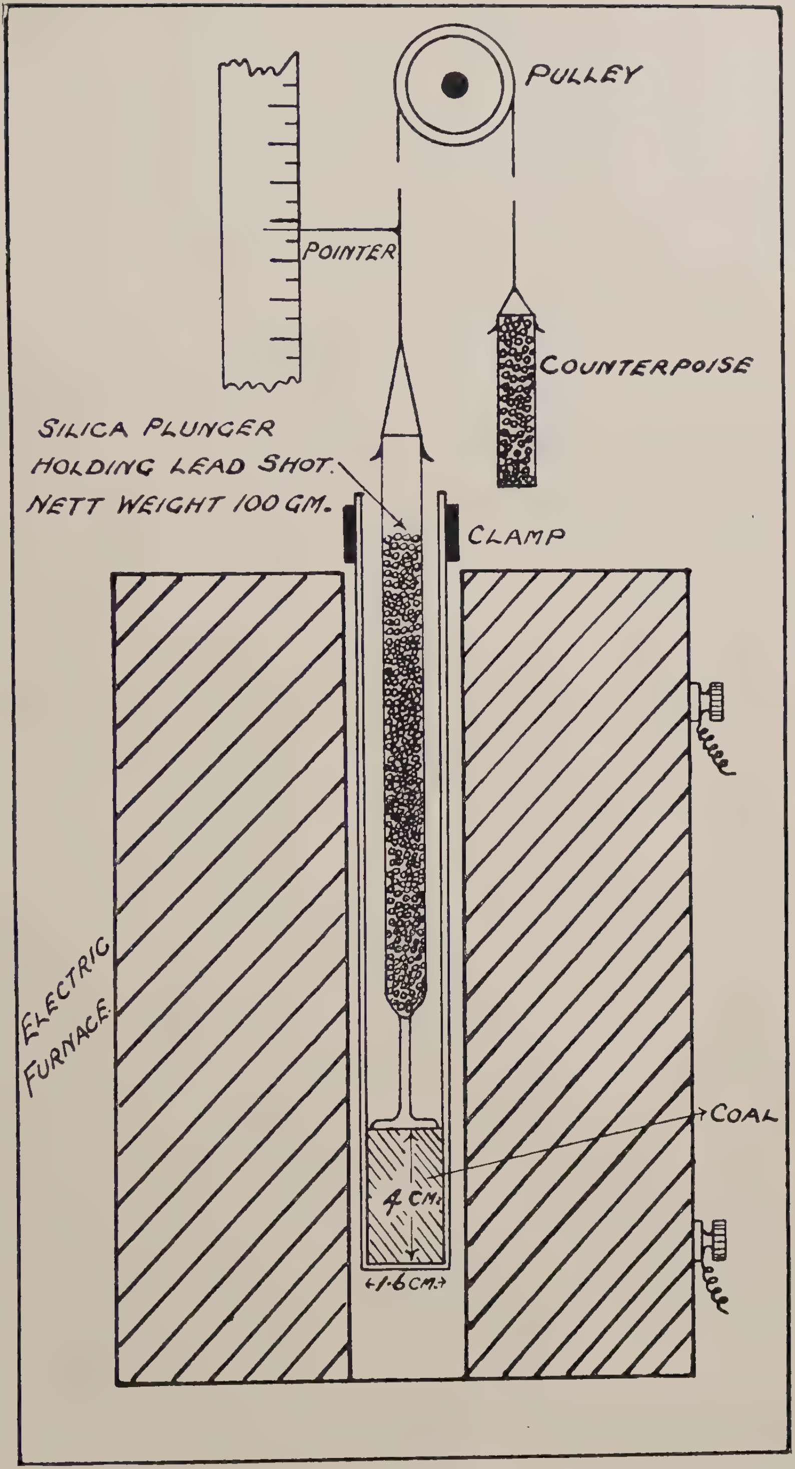

PULLEY
POINTER
COUNTERPOISE
SILICA PLUNGER HOLDING LEAD SHOT. NETT WEIGHT 100 GM.
CLAMP
ELECTRIC FURNACE
COAL
4 CM.
1·6 CM.

FIG. 48.—Diagram of Sheffield Laboratory Test for Studying the Contraction and Expansion of Coals.

be determined, the Silkstone coal can yield in practice a better coke than is at present usual.

On the whole, the relation between the percentage expansion of a coal, as determined by the test described, and the quality of the coke yielded by it in practice, is sufficiently good to warrant the test being employed to assess, roughly, the value of a coal for coking. The test is now being developed, along similar lines, in relation to the blending of coals.

In the chapters that follow, the methods of testing coke described in Part I of this Report are used to determine the effects of variations in the conditions of manufacture, such as the blending of the coal charge, the size of the coal, the method of charging the ovens and the rate of heating the ovens. When analysing the results of the tests, special attention has been paid to the size analyses and shatter indices of the cokes and their temperatures of combustion when burned under standard conditions.

CHAPTER II

THE INFLUENCE OF BLENDING

In England the blending of selected coals for coke-making is not practised to the same extent as on the Continent or in America, the reason being that in each of the English coalfields where coke is made there is not much difference in character between the various coals mined, as there is abroad. In the Westphalian coalfield, for example, the upper seams are relatively high in volatile matter, containg over 30 per cent., and are used as gas-making coals; in the middle coal measures, the coals, containing between 20 and 25 per cent. of volatile matter, are of special value for coke-making; whilst in the lower coal measures the coals contain less than 20 per cent. of volatile matter and are non-coking. Similarly, in France and Belgium, " fat " coals (" coking coals "), containing 20–30 per cent. of volatile matter, and " lean " coals (" non-coking coals "), containing less than 20 per cent. of volatile matter but of high carbon-content, are mined in the same areas if not from the same pits.

In the Continental coal-mining countries it is common practice to blend the " coking " and " non-coking " coals in definite proportions for coke-making. Special precautions have been found to be essential for the proper blending of the two types of coal, for a " pocket " of non-caking coal in the charge would merely produce breeze, and blending plant is installed where coals of different types are stored in separate hoppers from which they can be mixed in specified proportions. This is usually effected by regulating the rate of discharge of the coals from the hoppers on to belt conveyers which deliver them to the crushers, where mixing and crushing are carried out simultaneously.

In Great Britain, the South Wales coalfield alone provides an example of the low-volatile poor caking coals (steam coals) and caking coals (coking coals) found in juxtaposition being blended for coke-making. In the Durham coalfield, all the coals are coking coals of medium or fairly high volatile matter content, and coals from two or more seams are usually mixed together for coke-making. The coals being of similar type, their perfect admixture is of little importance and it is unusual to provide separate rail-roads and storage hoppers for the different seams. " Mixing " rather than " blending " is practised, and the proportions of the different seams delivered to individual ovens may vary considerably.

In the South Yorkshire area, the coals of all the seams, with the exception, in certain districts, of the Halifax Soft and the Better Bed, contain over 30 per cent. of volatile matter and each of them if carbonised separately would agglomerate in the coke-oven. In West Yorkshire, there are some non-coking coals which would not agglomerate on carbonisation. Whilst there is in South Yorkshire no single coal that is non-caking, many of them would yield such a high proportion of breeze if coked alone that it would not be profitable to charge them to the ovens and they must be classed as "non-coking." Such non-coking coals can, however, conveniently be mixed with recognised coking coals, for they do not remain entirely unagglomerated, as do low-volatile non-coking coals, if imperfectly blended. The mixing of seams for coking in South Yorkshire therefore does not demand separate storage accommodation for each seam, though this is sometimes provided.

At Lincolnshire coke-making plants, to which all the coals have to be brought, many different qualities of coals are carbonised, and here the provision of blending plants is desirable and is customary.

If low-volatile non-coking coals were available in the different coke-making districts of England, the blending, as distinct from the mixing, of coals would become more common, for experience has shown that these low-volatile coals are particularly valuable for blending purposes. Their function has not always been properly understood and the practice in different districts where such blending is carried out varies considerably. Sometimes the aim is to produce a blend of which the mean volatile matter content will be 20 per cent.; sometimes the mean aimed at is 22 per cent.; and sometimes 25 per cent. Thus it has often been concluded that the amount of volatile matter in the blend as charged to the ovens is, *per se*, of prime importance, a view which we have shown to be incorrect (p. 42).

From what we have said previously (p. 166), it will have been deduced that one of the principal virtues of a low-volatile non-coking coal as a blending material is, in all probability, its low oxygen-content. By reason of this low oxygen-content, the surfaces of the coal particles can become "wetted" with the minimum amount of binding material and the particles can thus be properly assimilated by the caking coal that forms the other ingredient of the blend.

The compositions of some low-volatile non-coking coals used abroad for blending with coking coals are recorded in Table LVIII.

TABLE LVIII.—ANALYSES OF SOME LOW-VOLATILE NON-CAKING COALS USED FOR BLENDING IN COKE MANUFACTURE.

Description of Coal.	Volatile Matter (less Moisture). (Per cent. on Dry Coal).	Ultimate Analysis. Per cent. on Ash-free, Dry Coal.		
		Carbon.	Hydrogen.	Oxygen.
Sonnenschein, Westphalia	14·0	89·7	4·3	5·0
Westende, Westphalia	16·4	92·1	4·6	1·3
Roche-la-Molière, France	14·0	89·2	4·4	4·3
Creuzot, France	15·8	89·9	4·2	3·8
Pocahontas, America	16·4	90·9	4·4	2·4

The steam coals used for blending with coking coals in South Wales have similar analyses.

In some countries, where low-volatile non-coking coals are not readily available, attempts have been made to produce a blending material having similar properties by the low-temperature carbonisation of caking coals. Before discussing the use of low-temperature coke, or char, for such a purpose, the blending of caking coals must be considered.

The Blending of a Caking Coal with a Caking Coal

It is often difficult to isolate single seams of coal at a colliery screening plant in such a manner as to enable large-scale coking tests to be made with each seam. For this reason, we have not hitherto been able to carry out many coking tests with single seams of coal. The standardisation of a "box test" in which 300 lb. of coal is used, and of a test with an experimental oven, carbonising about 5 cwt. of coal, both of which give results comparable with those of full-scale oven tests (see p. 228), will, however, enable this subject to be explored more fully in the future. Such full-scale oven tests as we have made are recorded in Table LIX. For each set of comparisons, the coking conditions, *e.g.* as regards method of charging and rate of heating, were the same.

Table LIX.—The Blending of Two or More Caking Coals.

(A) *The Coke from the Blend is of Poorer Quality than the Coke from either Coal.*

Coke No.	Coal.	Size Analysis of Coke (per cent.).					Shatter Indices.		
		On 4-in.	On 3-in.	On 2-in.	On 1½-in.	On 1-in.	2-in.	1½-in.	1-in.
19A	Barnsley and Haigh Moor	1	7	35	67	92	73	84	93
19B	Parkgate	0	11	49	81	95	68	82	93
19C	Barnsley and Haigh Moor 50% Parkgate 50%	0	7	32	65	89	65	81	92

(B) *The Coke from the Blend is the Average in Quality of the Coke from either Coal.*

Coke No.	Coal.	Size Analysis of Coke (per cent.).					Shatter Indices.		
		On 4-in.	On 3-in.	On 2-in.	On 1½-in.	On 1-in.	2-in.	1½-in.	1-in.
28A	Black Shale (Derby.)	27	45	76	86	93	61	67	80
28B	Tupton (Derby.)	14	38	85	92	96	63	72	87
28F	Black Shale and Tupton	29	53	75	84	92	57	70	85

(C) *The Coke from the Blend is of as Good Quality as the Coke from either Coal.**

Coke No.	Coal.	Size Analysis of Coke (per cent.).					Shatter Indices.		
		On 4-in.	On 3-in.	On 2-in.	On 1½-in.	On 1-in.	2-in.	1½-in.	1-in.
17K	Parkgate	69	87	95	97	98	79	89	95
17H	Barnsley	56	78	91	94	97	69	79	92
17I	Silkstone	73	82	90	93	96	62	73	88
17A	Parkgate 53% Barnsley 27% Silkstone 20%	60	80	91	95	97	82	90	95
29B	Parkgate and Silkstone	14	42	78	89	95	74	87	94
29D	Wath Wood and Swallow Wood	14	37	71	84	93	67	80	91
29F	Parkgate and Silkstone 80% Wath Wood and Swallow Wood 20%	18	38	72	85	94	73	86	95
18E	Flockton and Thorncliffe	44	75	93	96	98	75	84	92
18H	With 10% Barnsley	31	69	88	95	98	72	85	94
18I	With 27% Barnsley	44	79	90	95	98	71	81	91
18K	With 43% Barnsley	48	78	90	96	98	70	82	92

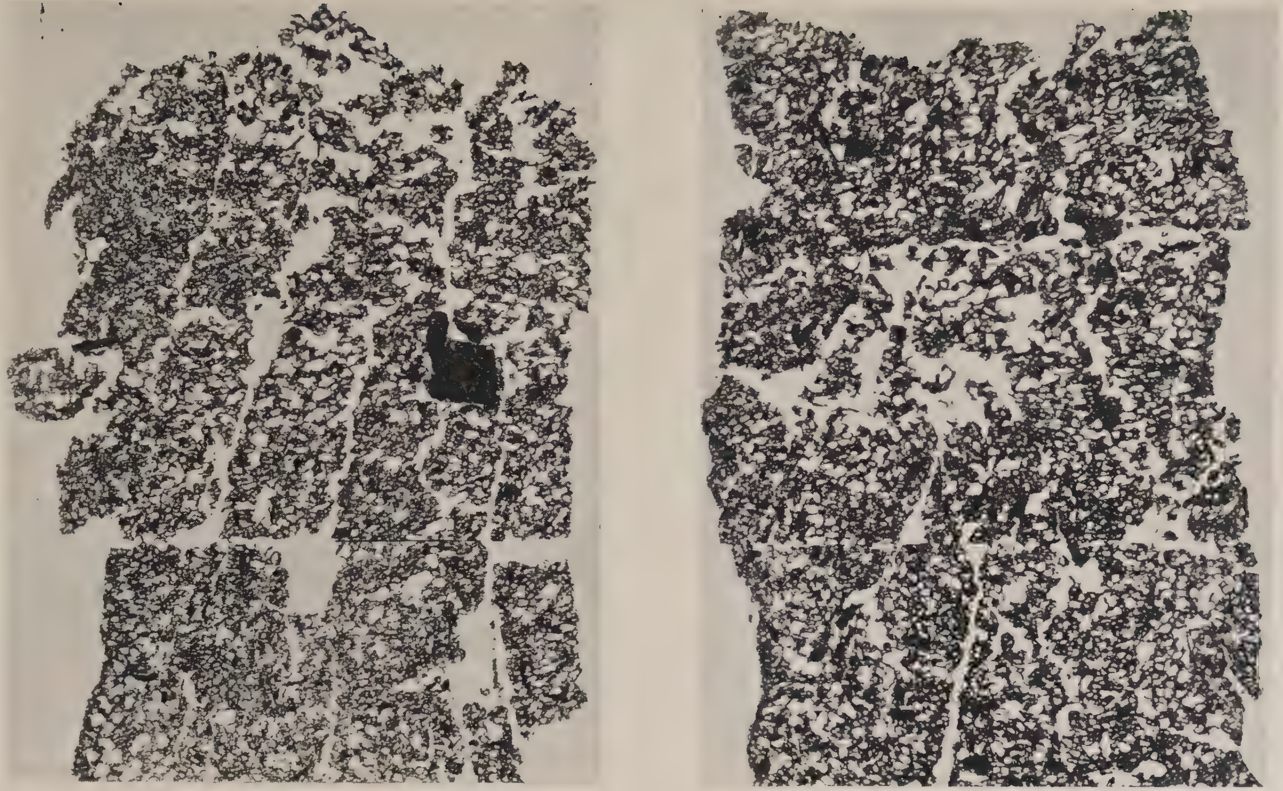
* There being but little difference in the size analyses in each set of tests, judgment is formed on the shatter indices (1½-in.) of the cokes.

In each instance the coals blended were from the same district, usually from the same pit. In the No. 18 and No. 29 series, the coal added to the good caking coal (or mixture of similar coals) was a poor caking coal. The coke from such blends was of as good a quality as that from the good caking coals alone. It is, however, impossible to generalise from these results, for each different coal requires separate consideration. In none of these tests did the addition of a high-volatile poor caking coal (of fairly high oxygen-content) effect an improvement, as regards hardness, in the coke normally obtained from the good caking coal alone. Such a result was, however, obtained under certain conditions. When the mixture of Flockton and Thorncliffe coals (see coke No. 18E) was coked in a 14-in. oven, the coke obtained was too spongy. On blending the Barnsley coal with the mixture, the sponginess was rectified and the hardness of the coke was improved, though its average size was less :—

Coke No.	Coal.	Size Analysis of Coke (per cent.).					Shatter Indices.		
		On 4-in.	On 3-in.	On 2-in.	On 1½-in.	On 1-in.	2-in.	1½-in.	1-in.
18A	Flockton and Thorncliffe	32	56	82	91	96	71	80	91
18L	With 20% Barnsley	1	13	74	90	96	69	87	95

UNIVERSITY COLLEGE,
MINING
DEPARTMENT
NOTTINGHAM.

[*To face p.* 182.



	No. 18A (high-volatile, strongly-caking coal).	18L (with 20% poorly-caking coal).
Total porosity . .	58·9	52·3
Shatter index (1½-in.) .	80	87

Plate XXXI.—The Influence of Blending Poorly-caking Coal on the Structure of the Centre-of-oven End of Cokes made at a Fast Rate of Heating. (Actual Size.)

The spongy centre-of-oven end of coke No. 18A is illustrated on Plate XXXI which also shows the improvement effected by the addition of a poor caking coal. Cokes 18E, 18H, 18I and 18K (Table LIX) were made in wide ovens and no advantage was apparently obtained by the blending of the Barnsley coal with the Flockton and Thorncliffe mixture, as when the fast coking 14-in. oven was used.

One result of blending coals from different districts may be quoted. Both coals were poor caking coals, one from Derbyshire and the other from the Barnsley seam, Doncaster :—

Coke No.	Coal.	Size Analysis of Coke (per cent.).					Shatter Indices.		
		On 4-in.	On 3-in.	On 2-in.	On 1½-in.	On 1-in.	2-in.	1½-in.	1-in.
22D	Deep Soft, Derby.	3	16	57	88	97	42	67	86
22B	With 30% Barnsley	19	51	80	92	98	48	66	87

There was no material alteration in the hardness of the coke but its size was improved by the blending.

The Blending of a Coking Coal with a Low-volatile Non-caking Coal

Most of the cokes from South Wales that we have tested have been made from blends of coking (medium-volatile) coals with steam (low-volatile) coals. The structures of several such cokes are illustrated on Plates VI and VII.

In most of the coking tests that we have made with blends of a coking coal with a non-caking coal we have used anthracite duff. A series of " box tests " using anthracite of less than ⅛-in. size blended with a South Yorkshire coking coal gave the following results :—

Coke No.	Anthracite in Blend (per cent.).	Shatter Indices.	
		2-in.	1½-in.
29B (*b*)	Nil	70	87
29L (*b*) i	10	69	85
29L (*b*) ii	20	75	88
29L (*b*) iii	30	85	90
29L (*b*) iv	40	73	86

The addition of 20 or 30 per cent. of anthracite thus improved the hardness of the coke, but a greater quantity made it weaker. Having determined by the box tests the optimum proportion of anthracite to use, large-scale oven tests were made to determine the effect of the rate of heating on the best blend. The results were as follow :—

Coke No.	Anthracite in Blend (per cent.).	Width of Oven (in.).	Coking Time (hr.).	Rate of Coking (in. per hr.).	Shatter Indices	
					2-in.	1½-in.
29B	Nil	21	22½	0·95	74	87
29C	Nil	14	12	1·15	66	85
29M	30	21	24½	0·85	72	90
29N	30	21	20½	1·00	67	84
29O	30	14	9½	1·45	53	74

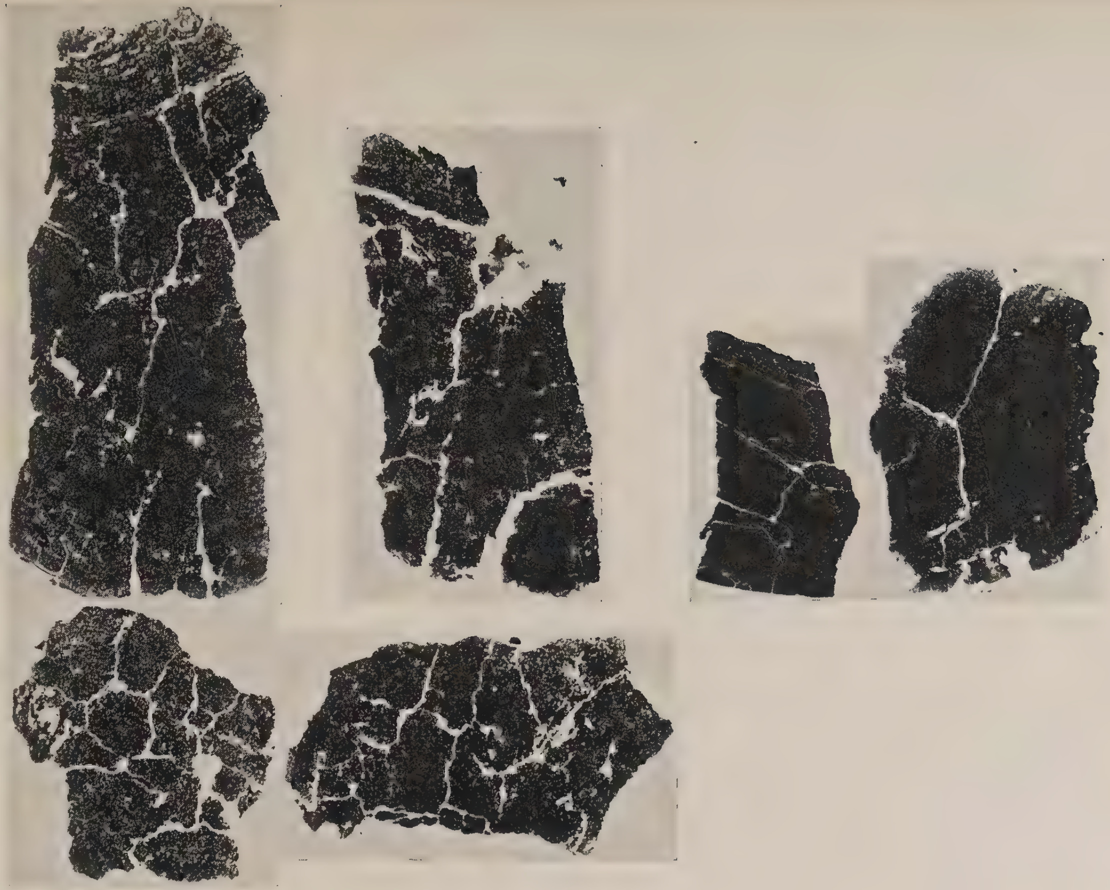
In the box tests the coking time had been 24 hours. With the same coking time in the full-scale oven tests, the 1½-in. shatter index of the coke from the 30 per cent. anthracite blend had the same value as in the box test. This rate of heating was too slow for the plant, demanding a reduction in the heat of the ovens. The "natural coking time" for the 21-in. ovens when coking the blend was found to be 20½ hours, but the coke produced was not so good as when the coking time was longer. With a still faster coking time, in the 14-in. ovens, the coke was further impaired, being inferior to that from the unblended coal.

In another test with a South Yorkshire coking coal, the addition of 20 per cent. of anthracite duff produced a coke which was discharged from the ovens in large pieces rarely less than 9-in. cube (see Plate XVIII). The outer shell of each of these coke lumps was very hard, but, once the shell had been broken, the inside crumbled rather readily. The shatter indices were: 2-in., 86; 1½-in., 89; 1-in., 93. With a normal coke having a 2-in. shatter index of 86, the 1½-in. index is about 93 and the 1-in. index about 97. The abrasion index of the anthracite blend coke explains its inferiority. It was 83·2 at the 1½-in. screen, with 6·0 per cent. of dust through $\frac{1}{16}$-in. For a normal coke having a 2-in. shatter index of 86, the abrasion index would be about 97, with about 1·0 per cent. of dust through $\frac{1}{16}$-in. The friability of the anthracite blend coke is evident from the reproduction on Plate XXXIII.

We have tested some cokes made from blends of a South Wales low-volatile coking coal with anthracite. Since we have no records regarding the coke made from the coking coal alone, the chief interest of the results lies in the information they give as to the structure of anthracite blend cokes. This is illustrated on Plate XXXII. For cokes Nos. 8A and 8B the proportions of anthracite were low, being 11 and 17 per cent., but for coke No. 25A the proportion was 67 per cent., and for coke No. 25B the mixture contained 33 per cent. of anthracite and 33 per cent. of steam coal. The fractures in the cokes differ from those in normal coals, tending to be fine and irregular cracks.

THE BLENDING OF COKING COALS WITH LOW-TEMPERATURE COKE

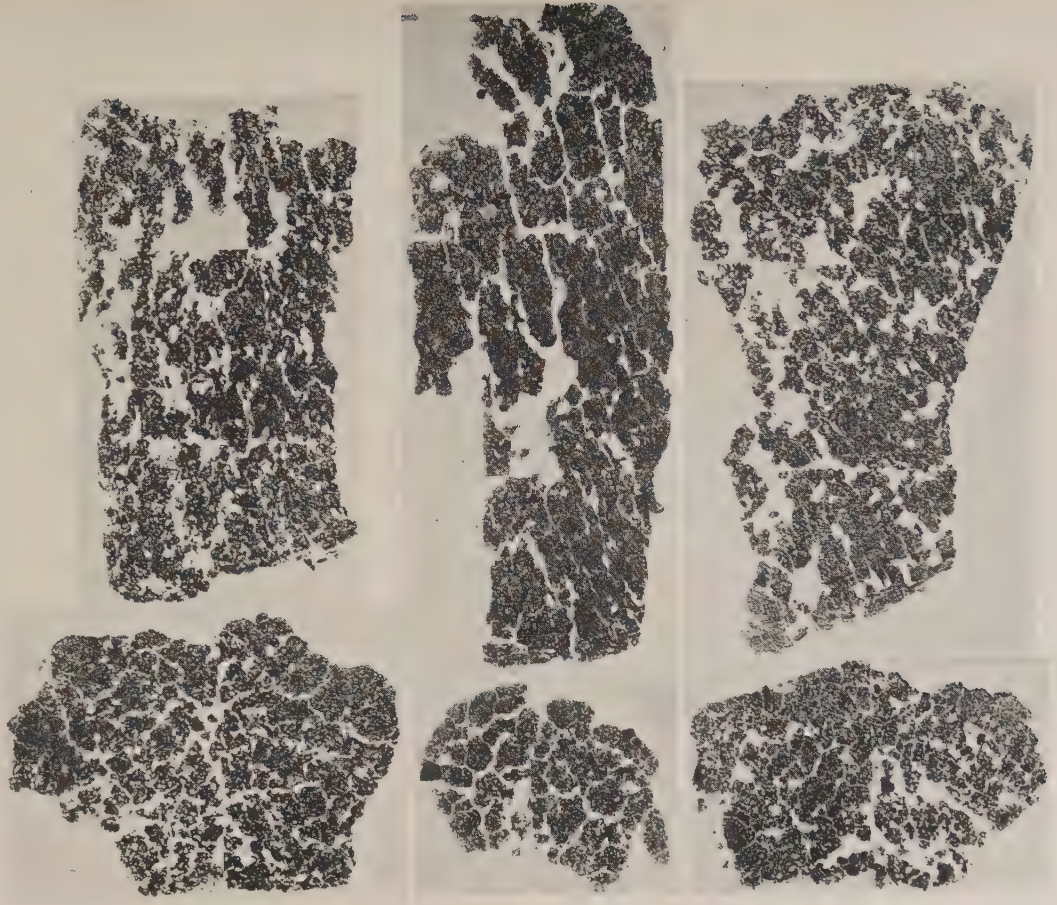
Bönnemann (*Gluckauf*, 1926, **62**, 1551) has recorded tests made to improve the quality of Silesian coke for which, in the absence of a low-volatile coal, low-temperature coke breeze was used. The



No. 8A. 8B. 25A. 25B.

Plate XXXII.—Structure of Anthracite Blend Cokes.

[*To face p.* 184.



No. 9. 22G. 38C (iv).

Plate XXXIII.—Blocky but Friable Cokes Produced by Blending with Non-caking Materials.

[*To face p.* 184.

coke made from Silesian coking coals alone had a trommel index (40 mm.) of 60, and when the oven charge contained 15 per cent. of low-temperature coke this was raised to 73. The low-temperature coke was prepared at 475° C. and contained from 17 to 19 per cent. of volatile matter.

In the Saar district the cokes made from "straight" coking coals are fingery and much inferior to Westphalian cokes. We have tested a "straight" Saar coke and one made from a blend containing 18 per cent. of low-temperature coke (through ⅛-in.) :—

Coke No.	Charge.	Size Analysis of Coke (per cent.).					Shatter Indices.			Abrasion Index.
		On 4-in.	On 3-in.	On 2-in.	On 1½-in.	On 1-in.	2-in.	1½-in.	1-in.	1½-in.
36A	Saar coking coal	24	43	62	73	87	65	75	86	99
36B	With 18% low-temp. coke breeze	22	52	85	94	97	80	93	97	98

The general improvement in the quality of the blend coke was marked. Although the proportion of large pieces was not altered, 97 per cent. of the blend coke was of over 1-in. size as compared with 87 per cent. for the straight coke. The hardness was increased to a remarkable degree. The structures of the two cokes are illustrated in Fig. 14. It will be seen that fractures have been almost eliminated from the blend coke.

TABLE LX.—THE BLENDING OF COKING COALS WITH LOW-TEMPERATURE COKE.

Coke No.	Charge.	Size Analysis of Coke (per cent.).				Shatter Indices.			Abrasion Index.
		On 4-in.	On 3-in.	On 1½-in.	On 1-in.	2-in.	1½-in.	1-in.	1½-in.
22F (Derby.)	Straight slack	19	31	79	90	62	74	87	91
22G	With 20% coke	66	79	89	93	72	79	87	72
38A (W. Yorks.)	Straight slack	15	31	70	84	55	72	85	97
38C i	With 9% coke	50	59	71	78	68	74	80	79
38C ii	With 12% coke	90	91	91	92	68	71	76	43
38C iii	With 18% coke	79	81	84	86	81	83	86	75
38C iv	With 22% coke	82	85	88	90	79	83	85	80
* 29B (S. Yorks.)	Straight slack	14	42	89	95	74	87	94	98
* 29J	With 20% coke	39	61	89	93	80	89	95	93
† 29C (S. Yorks.)	Straight slack	6	32	93	97	66	85	95	98
† 29K	With 20% coke	40	64	89	93	79	88	93	92

* 21-in oven. † 14-in. oven.

Similar improvement was anticipated for blends of low-temperature coke with British coals. None of the tests that we have made, however (see Table LX), have given such striking results as that with the Saar coal.

With the poor coking Derbyshire and West Yorkshire coals a considerable increase in the size of the coke was obtained by the admixture of low-temperature coke. The increase was most marked with the West Yorkshire coal, which was top-charged, blocks over two feet long being discharged from the ovens. With both these coals, however, the blend cokes were friable and obviously unsuitable for metallurgical use. The blocky but friable character of cokes Nos. 22G and 38C (iv) is illustrated on Plate XXXIII. The shatter indices were abnormal. The 2-in. index generally, and the 1½-in. index in some instances, was improved greatly, but the 1-in. index was hardly affected.

With the South Yorkshire good coking coal, on the other hand, the blending of low-temperature coke caused some improvement in the quality of the coke, which was larger and harder though rather more friable.

These marked differences in the results obtained on blending a similar material with different types of coking coals are noteworthy. The nature of the low-temperature coke may also be of importance, as will be shown later.

THE BLENDING OF COKING COALS WITH FUSAIN

During the course of our tests we noted that larger and harder cokes were made when clean slurry was coked alone than when the smalls from the same seam were used. Similar but smaller differences as regards hardness were noticed between the cokes made under the same conditions from crushed slack and from crushed large coal from the same seam. In these comparative series of tests, the only dissimilarity in the character of the charges lay in possible differences in the size of the material composing them and in the fact that fusain would tend to concentrate in the slurry (and in the crushed slack rather than in the crushed large coal). Experiments with different sizes of one of the coals did not indicate that the size of the particles composing the charge was of major importance. The probable influence of the fusain was therefore suspected. The results recorded in Table LXI illustrate the difference in quality of the coke when the charge contains slurry and when a crushed large coal is used instead of a crushed slack.

The letter (*b*) introduced in the coke number indicates that the coke was made in a box test (see p. 228). In all the large-scale oven tests, care was taken to obtain a representative sample of the coke from each oven (see p. 195) and the handling of the cokes after discharge and before testing was standardised. The shatter indices are the averages of from 6 to 8 tests on each coke.

The size analyses of the coals (Parkgate and Silkstone) charged for the 3E and 3F series of cokes are recorded in Table LXII.

TABLE LXI.—COMPARISON OF COKES MADE FROM SLACKS, SLURRIES AND CRUSHED LARGE COALS.

Coke No.	Charge.	Size Analysis of Coke (per cent.).				Shatter Indices.	
		4-in.	3-in.	1½-in.	1-in.	2-in.	1½-in.
17H (*b*)	Barnsley, slurry-free	88	92	98	99	81	84
17H (*b*) s	Barnsley slurry	79	93	98	99	87	93
17K (*b*)	Parkgate, slurry-free	74	84	96	98	81	89
17K (*b*) s	Parkgate slurry	87	94	99	99	86	93
38A	W. Yorks. coking coal, slurry-free	15	31	70	84	55	72
38A.s	Washed slurry of 38A	36	76	95	96	78	89
3E (VII)	Parkgate and Silkstone large coal crushed, through ¼-in.	8	33	89	96	77	89
3F (I)	Parkgate and Silkstone slack crushed, through ¼-in.	3	29	91	97	78	91
3E (VIII)	Parkgate and Silkstone large coal crushed, through ⅛-in.	13	40	88	95	79	88
3F (II)	Parkgate and Silkstone slack crushed, through ⅛-in.	4	25	92	98	80	92
3E (VI)	Parkgate and Silkstone large coal crushed, through $\frac{1}{16}$-in.	—	18	90	97	72	88
3F (*b*) s (i)	Parkgate and Silkstone slurry, unwashed	—	—	—	—	81	91
3F (*b*) s (ii)	Parkgate and Silkstone slurry, washed	—	—	—	—	88	93

TABLE LXII.—SIZE ANALYSES OF COALS CHARGED TO OVENS.

Coal No.		Size Analysis (per cent.).						
		Through 1/4-in.	Through 1/8-in.	Through 1/20-in.	Through 1/40-in.	Through 1/120-in.	Through 1/200-in.	Through 1/400-in.
3E (VII)	Crushed large coal	98·4	59·8	15·4	12·4	7·4	5·2	3·2
3F (I)	Crushed slack	100·0	60·6	37·1	19·3	8·5	5·7	3·1
3E (VIII)	Crushed large coal	100·0	100·0	69·7	41·6	17·2	12·0	6·2
3F (II)	Crushed slack	99·9	100·0	75·4	43·1	19·8	11·5	7·8
3E (VI)	Crushed large coal	100·0	99·7	92·6	51·9	19·1	13·0	6·6
3F (*b*) s (i)	Unwashed slurry	100·0	97·9	85·5	59·8	29·1	20·2	11·5
3F (*b*) s (ii)	Washed slurry	100·0	98·5	84·7	52·2	15·2	9·9	5·2

The size analyses of coals Nos. 3E (VII) and 3F (I) are similar and those of coals Nos. 3E (VIII) and 3F (II) are almost identical. Coal 3E (VI) contained a rather higher proportion of the finest sizes than the slurry 3F(*b*)s(ii). Differences in the size of the coal cannot therefore be held to account for the superior quality of the cokes from the crushed slacks and the slurries. The percentages of fusain in the finer sizes of the number of coal charges were therefore determined. A microscopical method was used, the distinctive character of the fusain particles rendering their evaluation a comparatively easy task. Some of the results are recorded in Table LXIII.

TABLE LXIII.—PERCENTAGES OF FUSAIN IN THE FINER SIZES OF COAL.

Coal No.		Fusain (per cent.).		
	Size of Coal (in.).	1/120–1/200.	1/200–1/400.	Through 1/400.
3E (VI)	(Crushed Parkgate and Silkstone large coal)	<1	<1	5
3E (VII)		<1	<1	10
3E (VIII)		Nil	2	15
3F (I)	(Crushed Parkgate and Silkstone slack)	2	4	40
3F (II)		1	1	20
3F (IV)		<1	5	30
3G (I)	(Crushed slack)	2	2	50
3G (II)		2	2	50

Taken in conjunction with the size analyses of the coals, these results show that the charges of crushed large coal contained on the average only about 0·6 per cent. by weight of fusain as compared with about 1·5 per cent. in the crushed slacks from the same seams.

If during the coking process fusain plays the *rôle* that we have ascribed to it (see p. 42), it can be understood that quite a small proportion by weight would provide a sufficiency of particles, differing in character from the remainder of the charge, capable of acting as nuclei for the inception of contraction.

On this hypothesis it could be argued that low-temperature coke of suitable character, ground to the same size as fusain (*i.e.* about $\frac{1}{400}$-in.), should be equally effective. On putting this to test, it was found to be so. The results of the experiments (box tests) are recorded in Table LXIV. The coal used was Parkgate and Silkstone slack and the low-temperature coke was made from the same coal at a temperature not exceeding 450° C. In comparative experiments, finely-ground ($\frac{1}{400}$-in.) Parkgate and Silkstone slack was added to the charge instead of the coke.

About 80 per cent. of the Parkgate and Silkstone slack passed through a $\frac{1}{8}$-in. screen. On adding to the charge a small quantity of the same coal ground to $\frac{1}{400}$-in. size, the size and hardness of the coke were reduced; but on adding similar small quantities of finely-ground low-temperature coke from the same coal, the size of the resultant coke was considerably increased and its hardness was improved. The addition of too much of the ground coke was detrimental.

TABLE LXIV.—THE BLENDING OF A COKING COAL WITH FINELY-GROUND LOW-TEMPERATURE COKE.

Coke No.	Charge	Size Analysis of Coke (per cent.).				Shatter Indices.	
		On 4-in.	On 3-in.	On 1½-in.	On 1-in.	2-in.	1½-in.
29B (*b*)	Parkgate and Silkstone slack	16	38	86	93	70	87
29P (*b*) I (i)	With 2½% ground slack <1/400-in.	27	47	73	82	67	82
29P (*b*) I (ii)	With 5% ground slack <1/400-in.	21	40	81	89	62	82
29Q (*b*) I (i)	With 1% ground coke <1/400-in.	38	53	85	92	70	88
29Q (*b*) I (ii)	With 2½% ground coke <1/400-in.	56	66	87	94	81	91
29Q (*b*) I (iii)	With 5% ground coke <1/400-in.	35	59	93	96	59	82

The Use of Dust Rich in Fusain.—Further box tests were now made in which fusain additions were made to the coal charges by using the fine dust collected during screening, which is rich in fusain. The size analyses and fusain-contents of this dust were as follow :

Size (I.M.M. mesh).	On 5.	5–10.	10–20.	20–60.	60–100.	100–200.	Through 200.
Per cent., by weight .	0·3	1·5	14·5	30·6	10·8	9·0	33·3
Fusain in each fraction, per cent. . .	—	1	1·5	3·5	—	50	70

The fusain was concentrated in the finer sizes of dust, its proportion of the whole dust being about 30 per cent. This dust was blended with Parkgate and Silkstone slack in such proportions that the fusain-contents of the charges ranged from 1·5 to 6 per cent. The results of the tests are recorded in Table LXV.

TABLE LXV.—THE BLENDING OF A COKING COAL WITH COAL DUST RICH IN FUSAIN.

Coke No.	Charge.	Size Analysis of Coke (per cent.).				Shatter Indices.	
		On 4-in.	On 3-in.	On 1½-in.	On 1-in.	2-in.	1½-in.
29B (*b*)	Parkgate and Silkstone slack	16	38	86	93	70	87
29S (*b*) ii	With 1·5% fusain	57	69	86	92	74	90
29S (*b*) iii	With 3·0% fusain	52	68	86	94	81	91
29S (*b*) iv	With 4·5% fusain	71	79	92	96	79	90
29S (*b*) v	With 6·0% fusain	52	76	94	96	72	89

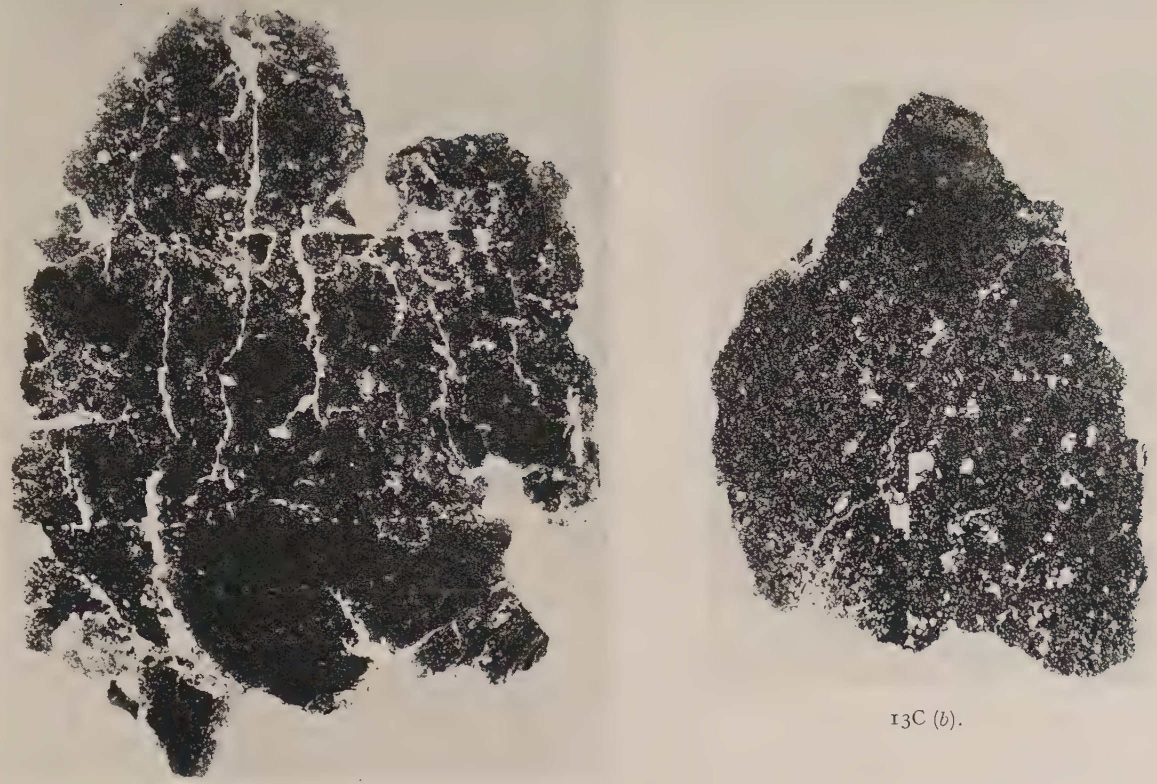
The effect on the size of the coke of the addition of a small proportion of fusain is remarkable, and the hardness is also improved. The results suggest, as did those with low-temperature coke dust (Table LXIV), that there is an optimum addition of fusain of about 3·0 per cent.

The Use of Slurries.—That the addition of fusain should be beneficial might appear, at first sight, out of keeping with the well-known detrimental effect on the quality of coke of slurry additions to the coal charge, for slurry usually contains a high proportion of fusain. It is not usual, however, to distribute wet slurry uniformly through the charge. It would, in fact, be difficult to do so. It therefore forms local patches of non-caking or poor caking material which merely create lines of weakness and form breeze when the coke is discharged. The cokes illustrated on Plate XXXIV demonstrate this. One was made from a silt, or fine slurry, and the other from the dry dust (extracted before washing) from the same seam. The fusain has collected in patches in the slurry coke, forming dense aggregates and causing weakness. In Table LXVI tests of this coke are compared with those made on the coke prepared from dry dust (from the same seam), in which the fusain is evenly distributed, and on cokes made from slacks intimately mixed with dust.

TABLE LXVI.—COKES MADE FROM SETTLED SLURRY, FROM DRY DUST AND FROM SLACKS BLENDED WITH DUST.

Coke No.	Charge.	Size Analysis of Coke (per cent.).				Shatter Indices.	
		On 4-in.	On 3-in.	On 1½-in.	On 1-in.	2-in.	1½-in.
13D (*b*) s	Settled slurry	14	36	71	80	62	77
13C (*b*)	Dry dust (19% fusain)	81	91	95	96	89	93
13E (*b*)	Coking slack	65	84	97	98	75	87
13F (*b*) i	Coking slack with 5% dust (*i.e.* 0·75% fusain)	63	79	91	94	79	90
13F (*b*) ii	With 10% dust (*i.e.* 1·5% fusain)	71	84	92	94	81	90
13F (*b*) iii	With 20% dust (*i.e.* 3·0% fusain)	67	81	92	93	86	93
13F (*b*) iv	With 33% dust (*i.e.* 5% fusain)	95	96	98	99	88	92
13F (*b*) v	With 50% dust (*i.e.* 7·5% fusain)	90	96	99	99	92	95

Fusain evidently has no value in coke-manufacture unless it is evenly distributed throughout the charge. Moreover, it appears that the beneficial effect of the fusain is diminished if too much is present. In this connexion, attention should be drawn to coke No. 38A.s (see Table LXI), an excellent coke made from the washed slurry of a poor coking coal. In this slurry the fusain was evenly



No. 13D (*b*) s.

13C (*b*).

Plate XXXIV.—Comparison of Structure of Cokes made from Slurry and Dry Dust.

[*To face p.* 190.

distributed by reason of its passage through the various troughs of a Rheolaveur slurry washer and excess of fusain had been removed by water-sprays at a dewatering screen. Table LXVII records the proportions of fusain in several slurries and dusts that we have examined, including the slurry from which coke No. 38A.s was made.

TABLE LXVII.—THE FUSAIN-CONTENTS OF SLURRIES AND DUSTS.

Size (I.M.M. mesh).	Dry Dust (13C (*b*)).		Slurry (13D (*b*)s).		Washed Slurry (38A.s).		Slurry Washer Refuse (cf. Washed Slurry).	
	Weight (per cent.).	Fusain in Fraction (per cent.).	Weight (per cent.).	Fusain in Fraction (per cent.).	Weight (per cent.).	Fusain in Fraction (per cent.).	Weight (per cent.).	Fusain in Fraction (per cent.).
On 20	3·6	—	6·4	Not determind	36·8	<1	—	—
20–60	37·6	1	27·4		50·0	1	1	1
60–100	25·4	5	15·8		5·3	3	22	3
100–200	10·1	25	10·1		4·7	10	34	7
Through 200	23·3	70	40·3	50	3·2	50	43	25
Fusain, per cent. on total	-	19	—	—		3·6		14

The Use of Fusain Alone.—Experiments were now made on the coking of blends with supplies of fusain collected for the purpose. Fusain in fairly large pieces and reasonably "pure" could be collected at the screens, at one colliery. Size analyses of two bulk samples of this material were made and the actual proportions of fusain in each size determined :—

Size (in.).	On ½	On ¼	On ⅛	On 1/10	On 1/20	On 1/40	On 1/120	On 1/200	On 1/400	Through 1/400
Per cent. by weight :										
Sample I	12·2	24·3	12·5	4·6	9·9	7·6	8·4	3·0	4·6	12·9
Sample II	21·2	24·7	11·8	4·2	10·5	6·6	5·3	2·1	2·1	11·5
Fusain in each fraction, per cent. :										
Sample I	About 50						50	60	75	75
Sample II	About 50						70	90	90	90

The average fusain-content of the samples collected was taken to be 66 per cent. The samples were ground in a ball mill until over 90 per cent. was of less than $\frac{1}{400}$-in. size. This ground fusain was then blended in different proportions with Parkgate slack (about 80 per cent. through ⅛-in.) and coked in "box tests." The results are recorded in Table LXVIII.

TABLE LXVIII.—THE BLENDING OF A COKING COAL WITH FUSAIN.

Coke No.	Charge.	Size Analysis of Coke (per cent.).				Shatter Indices.	
		On 4-in.	On 3-in.	On 2-in.	On 1½-in.	2-in.	1½-in.
13H (*b*)	Parkgate slack	49	84	95	97	79	88
13G (*b*) i	With 0·7% fusain	70	83	93	95	79	88
13G (*b*) iii	With 2·0% fusain	57	86	94	96	82	90
13G (*b*) v	With 3·3% fusain	79	89	97	98	83	91

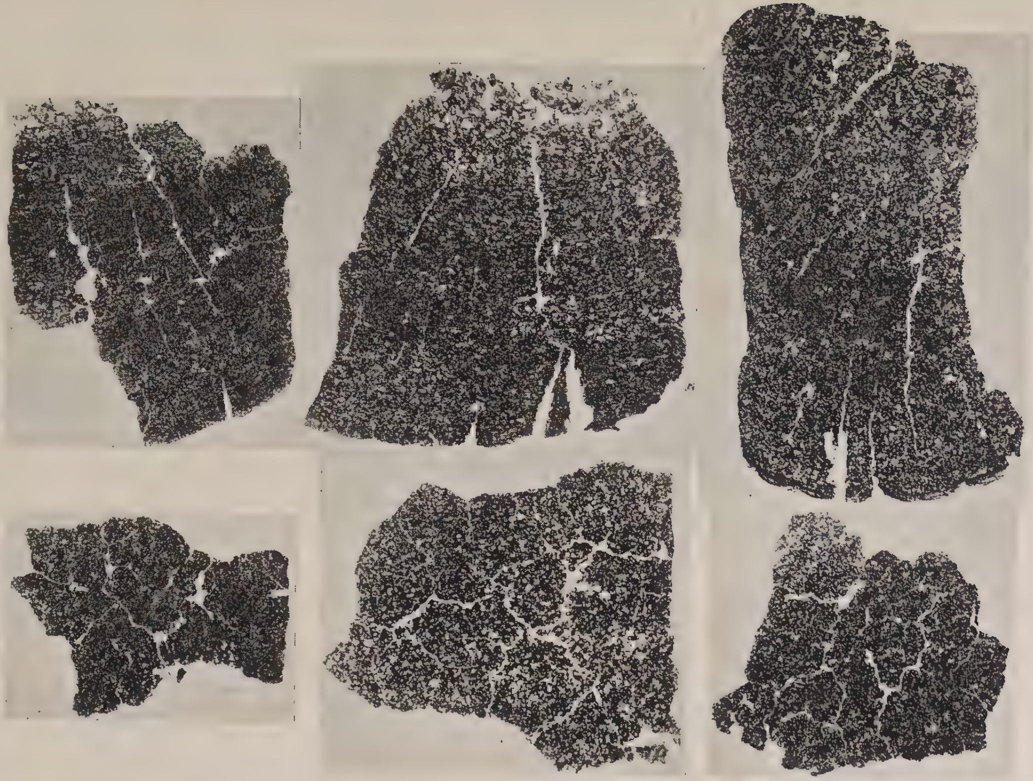
Although the size of the cokes was considerably increased by these small additions of fusain, there was not such a marked improvement in their hardness as when dust rich in fusain was used to introduce similar additions to the charge (see Table LXVI), perhaps because as little as two or three per cent. of fusain dust could not be uniformly mixed with the slack.

The Use of Fusain Diluted with Coal Dust.—Further coking tests were therefore made, in which the fusain was first "diluted" with dust obtained by grinding the Parkgate coal to $\frac{1}{400}$-in. size. Control tests, in which the ground Parkgate coal alone was added to the slack, were also made. The results are recorded in Table LXIX.

TABLE LXIX.—THE BLENDING OF A COKING COAL WITH FUSAIN.

Coke No.	Charge.	Size Analysis of Coke (per cent.).				Shatter Indices.	
		On 4-in.	On 3-in.	On 2-in.	On 1½-in.	2-in.	1½-in.
13H (*b*) r_4	Parkgate slack	53	74	87	93	77	86
13M (*b*) i	With 2% Parkgate dust	52	69	88	93	74	86
13M (*b*) ii	With 4% Parkgate dust	53	73	90	94	74	87
13M (*b*) iii	With 6% Parkgate dust	54	78	89	94	74	86
13M (*b*) iv	With 10% Parkgate dust	42	64	84	91	76	86
13G (*b*) v (r_3)	With 3·3% fusain	66	78	94	96	77	88
13G (*b*) vi (r_2)	With 5·0% fusain	61	84	91	95	77	90
13L (*b*) i	With 16·6% Parkgate dust and 3·3% fusain	65	83	93	95	82	89
13L (*b*) ii	With 25% Parkgate dust and 5·0% fusain	53	84	94	96	82	91

This series of tests served to show that: (1) The presence of finely-ground Parkgate coal mixed with the Parkgate slack had no



	No. 29Q (*b*) iii.	29S (*b*) iii.	13F (iv).
Blended with	2½% low temp. coke dust < $\frac{1}{400}$ in.	2½% fusain.	4% fusain.

PLATE XXXV.—Structure of Hard Cokes Produced by Blending with Fusain and Fusain-substitutes.

[*To face p.* 192.

effect on the quality of the coke produced; (2) the addition of small quantities of fusain in a fine state of division increased both the size and the hardness of the coke; and (3) the "dilution" of the fusain with coal dust before blending it with the Parkgate slack rendered the fusain more effective.

The Use of Fusain Substitutes.—Reference has already been made to the use of one substitute for fusain, namely, low-temperature coke breeze (see Table LXIV). The breeze from high-temperature coke has been used in a similar manner, with the results recorded in Table LXX.

TABLE LXX.—THE BLENDING OF A COKING COAL WITH HIGH-TEMPERATURE COKE DUST.

Coke No.	Charge.	Size Analysis of Coke (per cent.).				Shatter Indices.	
		On 4-in.	On 3-in.	On $1\frac{1}{2}$-in.	On 1-in.	2-in.	$1\frac{1}{2}$-in.
13H (*b*) r$_5$	Parkgate slack	67	80	96	97	73	87
13P (*b*) i	With $2\frac{1}{2}$% Parkgate coke dust	64	78	96	98	78	89
13P (*b*) ii	With 5% Parkgate coke dust	81	89	96	98	87	90
13P (*b*) iii	With $7\frac{1}{2}$% Parkgate coke dust	85	91	97	98	87	91

The Parkgate coke was ground so that all of it was less than $\frac{1}{400}$-in., *i.e.*, of a size comparable with that of fusain, and the experiments show that this fine coke dust when mixed with the coal charge in suitable proportion had an effect on the quality of the coke similar to that of fusain.

In other series of tests, high-temperature coke dust has proved ineffective and it appears that the character of the coal from which the coke was made is of importance. The study of the qualities desirable in substitutes for fusain is being continued.

Examples of hard cokes made by blending coking coals with fusain or substitutes for fusain are illustrated on Plate XXXV.

Tests with a Derbyshire Coal.—Small additions of fusain having been found to be so beneficial to the quality of the coke from a Yorkshire good coking coal, similar tests were made with a poor coking coal from Derbyshire. The results are recorded in Table LXXI.

The fusain was obtained from a cyclone collector and the dust from a good coking coal (Parkgate) was associated with it. Tests in which this dust, without fusain, was added to the Derbyshire slack did not indicate that it alone could materially improve the quality of the coke, but when fusain was present the improvement, both in size and hardness, was marked. Apparently, the optimum amount of fusain was 3 per cent.

TABLE LXXI.—THE BLENDING OF A POOR COKING COAL WITH FUSAIN.

Coke No.	Charge.	Size Analysis of Coke (per cent.).				Shatter Index.	
		On 4-in.	On 3-in.	On 2-in.	On 1½-in.	2-in.	1½-in.
22O (*b*)	Derbyshire slack	30	55	80	87	72	85
22P (*b*) ii	With 3% Parkgate coal and 1% fusain	56	78	92	95	74	88
22P (*b*) iii	With 6% Parkgate coal and 2% fusain	76	82	88	90	77	88
22P (*b*) iv	With 9% Parkgate coal and 3% fusain	76	89	95	97	78	90
22P (*b*) v	With 12% Parkgate coal and 4% fusain	66	84	92	93	79	90
22O (*b*) r.i	Derbyshire slack	55	74	87	91	69	81
22Q (*b*) i	With 3% Parkgate coal	73	86	93	95	73	84
22Q (*b*) ii	With 6% Parkgate coal	63	81	91	94	72	84
22Q (*b*) iii	With 9% Parkgate coal	46	66	81	87	71	83

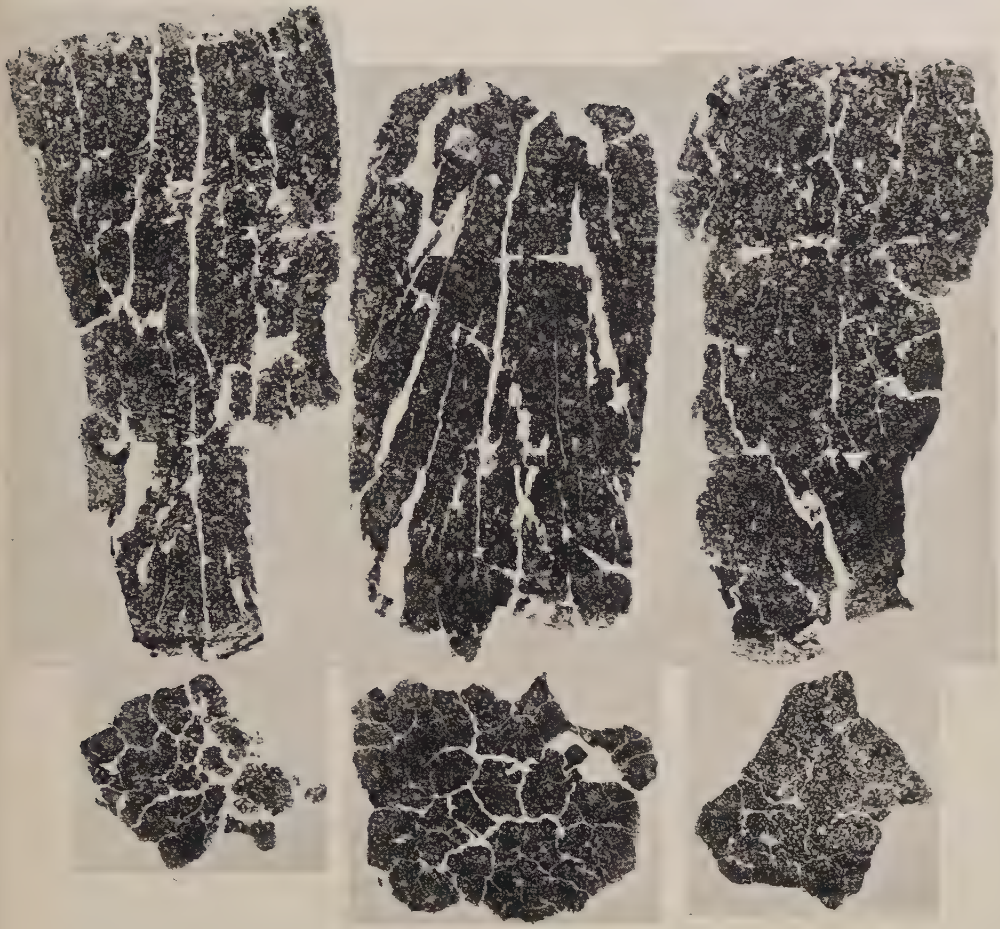
At the plant where this Derbyshire coal is coked the ovens are cake-charged. It will be shown later (Chapter IV) that an improvement in the quality of the coke can often be effected by top-charging the coal in preference to cake-charging. The dual effect of top-charging the coal and of adding 3 per cent. of fusain to the charge was therefore tried in full-scale oven tests. The results are recorded in Table LXXII.

TABLE LXXII.—THE EFFECT OF TOP-CHARGING A DERBYSHIRE COAL BLENDED WITH FUSAIN.

Coke No.	Conditions.	Size Analysis of Coke (per cent.).					Shatter Indices.	
		On 4-in.	On 3-in.	On 2-in.	On 1½-in.	On 1-in.	2-in.	1½-in.
22M	Cake-charged	5	21	58	77	90	46	68
22L	Top-charged	11	36	70	82	90	63	81
22P (iv)	Blended with 3% fusain and top-charged	19	50	82	90	94	74	88

The coke made from the fusain blend was blocky and but little fractured, in marked contrast to the fingery and brittle coke made from the coal alone when cake-charged. The differences between the cokes are illustrated on Plate XXXVI.

The work here described is being continued.



No. 22L. 22M. 22P (*b*) iv.

PLATE XXXVI.—Improvement of Derbyshire Coke by Top-charging and Blending with Fusain.

[*To face p.* 194.

CHAPTER III

THE INFLUENCE OF THE SIZE OF THE COAL

Some results were recorded in Part I, Chapter I (Table V) illustrative of the influence of the size of the coal on the size of the coke made from it. In considering this subject further, it is convenient to differentiate between the use of " graded " sizes of coal, where an upper and a lower limit of size is specified, and " through " sizes, where the upper limit only is specified and the proportions of smaller-sized coal are recorded.

Graded Sizes of Coal

Carefully-graded sizes of coal are of little value in actual coke-oven practice, but tests made with them provide data not otherwise obtainable and serve to contrast gas-works practice, in which graded coal is commonly used, with coke-oven practice, in which the charge is of " through " size.

Several graded sizes of coal, of a mixture of two similar seams, were prepared by hand-screening a number of wagon-loads of washed nuts. To obtain the smaller grades, the nuts were first passed through a Sturtevant crusher. These graded sizes, of approximately 1–$\frac{1}{2}$-in., $\frac{1}{2}$–$\frac{3}{8}$-in., $\frac{3}{8}$–$\frac{1}{4}$-in., $\frac{1}{4}$–$\frac{1}{8}$-in. and $\frac{1}{8}$–$\frac{1}{16}$-in., were top-charged to a regenerative oven of 20 inches mean width and heated during 30 hours.

When sampling the coke, about one-quarter of the charge was pushed on to one end of the coke car. The ram was then stopped, the car moved until its other end was opposite the oven, and a complete vertical section, representing about 2 ft. length of the oven, then separately discharged. The car was then moved back to its former position and the discharge of the oven completed. After quenching, the sample was passed over a $1\frac{1}{4}$-in. bar screen and loaded into a wagon, whence it was bagged. This procedure provided representative samples collected in a standard manner and ensured that the samples received the handling normal to the plant where the tests were carried out.

The size analyses of the cokes from the graded coals are recorded in Table LXXIII. The results are usually averages from six bags of coke.

The size of the coke is improved as the size of the graded coal is decreased, the improvement being marked until the maximum size of the graded coal is reduced to $\frac{1}{4}$-in.

The records in Table LXXIII represent the sizes of the cokes after they had been dropped on to the coke car and loaded into wagons. They therefore show, in part, the resistance of the cokes

TABLE LXXIII.—THE SIZE OF COKE MADE FROM GRADED SIZES OF COAL.

Coke No.	Coal.	Grade (in.).	Size Analysis of Coke.				
			On 3-in.	On 2-in.	On 1½-in.	On 1-in.	On ½-in.
3E (I)	Parkgate and Silkstone	1–½	12·9	40·0	63·5	84·1	94·3
3E (II)		½–⅜	26·4	51·2	68·9	85·9	93·9
3E (III)		⅜–¼	27·9	58·6	75·1	89·9	96·2
3E (IV)		¼–⅛	28·8	68·5	83·4	93·5	97·7
3E (V)		⅛–1/16	20·0	67·4	86·2	96·6	98·9

to breakage. So far as concerns their massiveness (represented by the on 3-in. sizes), but little alteration dependent on the size of the coal used is apparent. The relationship between the percentages of on 2-in., on 1½-in., on 1-in. and on ½-in. coke to their hardness is apparent from the shatter indices recorded in Table LXXIV.

TABLE LXXIV.—AVERAGE SHATTER INDICES OF COKES MADE FROM GRADED SIZES OF COAL.

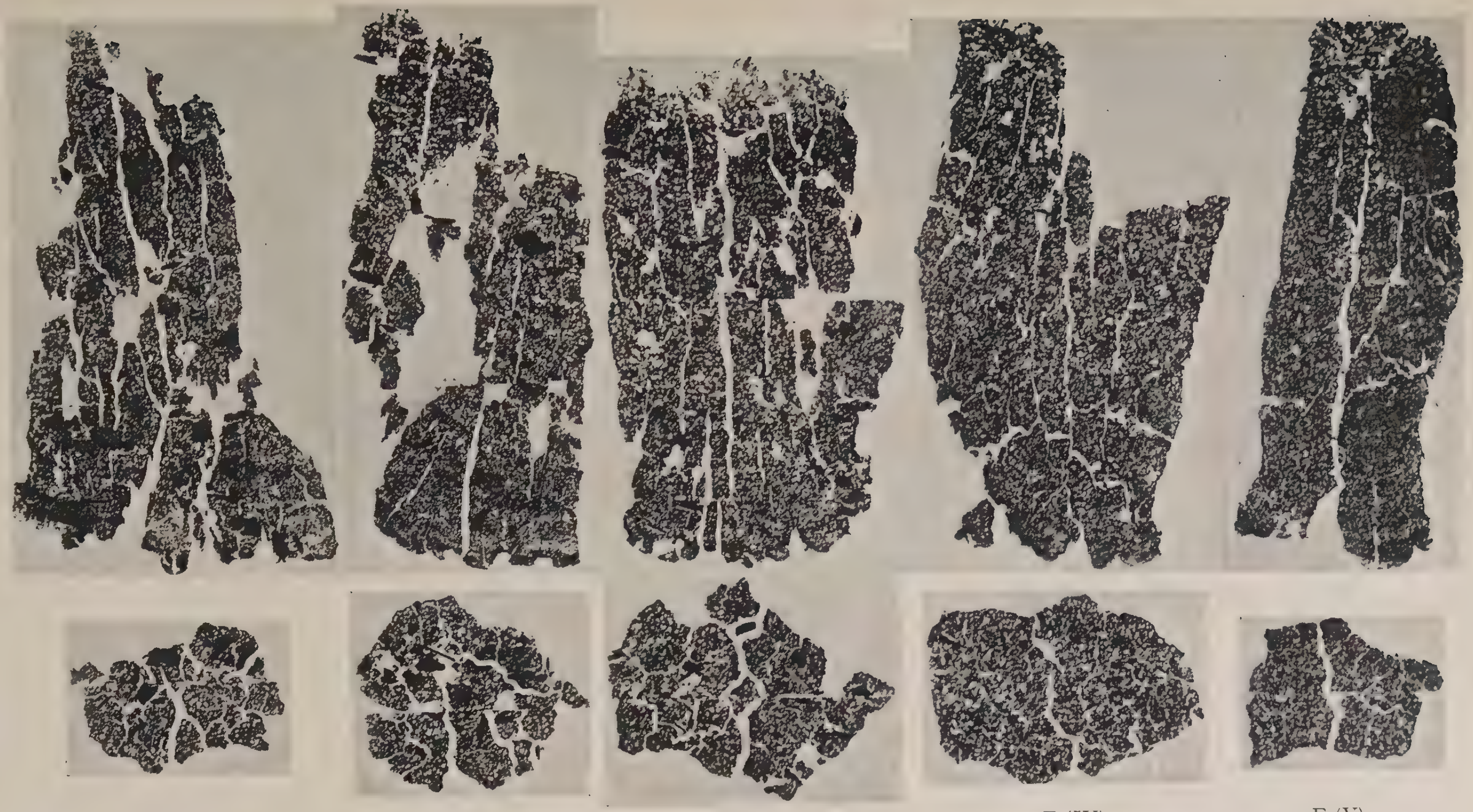
Coke No.	Grade (in.).	Shatter Indices.			
		2-in.	1½-in.	1-in.	½-in.
3E (I)	1–½	48·2	66·4	82·5	92·9
3E (II)	½–⅜	51·9	68·1	83·1	93·2
3E (III)	⅜–¼	56·1	73·1	86·4	95·5
3E (IV)	¼–⅛	69·0	81·9	90·6	97·2
3E (V)	⅛–1/16	72·3	86·3	94·9	98·3

There is a progressive increase in the hardness of the coke as the size of the coal is decreased, the increase being most marked when the grade is reduced from ⅜–¼-in. to ¼–⅛-in. When it is borne in mind that the massiveness of the cokes (as evinced by the on 3-in. size) is not much modified by variation in the size of the coal used, it would seem reasonable to assume that the general improvement in the size analyses of the cokes as the size of the coal is decreased is due mainly to their increased resistance to fracture. Plate XXXVII shows that the cokes made from the smaller sizes of coal have a more regular structure and that there are fewer fractures in them.

THROUGH SIZES OF COAL

In common coke-oven practice, that portion of the coal mined that passes through, say, a ½-in. screen is taken as the "coking slack." This is usually crushed before it is charged to the ovens so that nearly all of it passes through a ¼-in. screen and between 60 and 90 per cent., dependent on the degree of crushing, a ⅛-in. screen.

We therefore prepared "through" sizes of coal in which :



No. 3E (I). 3E (II). 3E (III). 3E (IV). 3E (V).

Size of coal (in.) 1–$\frac{1}{2}$. $\frac{1}{2}$–$\frac{3}{8}$. $\frac{3}{8}$–$\frac{1}{4}$. $\frac{1}{4}$–$\frac{1}{8}$. $\frac{1}{8}$–$\frac{1}{16}$.

PLATE XXXVII.—Effect of Graded Coal Size on the Structure of Coke.

[*To face p.* 196.

(1) all passed a ¼-in. and 60 per cent. a ⅛-in. screen (as in the "coarse crushing" of practice); (2) all passed a ⅛-in. screen (approximating to the "fine crushing" of practice) and (3) all passed a 1/16-in. screen; *i.e.* much finer crushing than is attempted in practice.

For direct comparison with the results obtained with graded sizes of coal, Parkgate and Silkstone nuts were used for the preparation of "through" sizes. In later tests, the usual coking slack from the Parkgate and Silkstone seams was crushed in a manner representative of "coarse" and "fine" crushing, whilst a further, coarsely-ground, sample yielding 60 per cent. through ⅛-in. but containing 20 per cent. of ¼–½-in. sizes was used to determine the effect of increasing the maximum size of coal in the charge. Finally, the slack from a mixture of two poor caking coals was used, "coarse crushing" being compared with "fine crushing."

The size analyses of the cokes made from these "through" sizes of coal, as loaded into wagons in the normal manner, are recorded in Table LXXV, and their shatter indices in Table LXXVI.

TABLE LXXV.—SIZE ANALYSES OF COKES MADE FROM THROUGH SIZES OF COAL.

Coke No.	Coal Used.	Grading of Coal Charged.	Size Analyses.					
			On 4-in.	On 3-in.	On 2-in.	On 1½-in.	On 1-in.	On ½-in.
3E (VII)	Parkgate and Silkstone nuts	Through ¼-in.; 60% through ⅛-in.	7·8	32·9	76·2	89·3	96·1	98·4
3E (VIII)		Through ⅛-in.	13·5	39·9	77·9	88·5	95·4	97·6
3E (VI)		Through 1/16-in.	Not determined	17·8	69·7	89·9	97·0	98·7
3F (IV)	Parkgate and Silkstone slack	Through ½-in.; 80% through ¼-in.; 60% through ⅛-in.	7·1	27·1	72·1	85·9	95·1	98·0
3F (I)		Through ¼-in.; 60% through ⅛-in.	3·1	28·6	76·5	91·0	97·1	98·4
3F (II)		Through ⅛-in.	4·4	25·1	75·3	92·3	97·9	98·9
3G (I)	Wath Wood, High Hazel and Barnsley slack	Through ¼-in.; 60% through ⅛-in.	14·3	39·8	76·8	88·0	94·5	96·9
3G (II)		Through ⅛-in.	5·1	16·8	66·1	86·2	94·0	95·9

On comparing the results for the "through" sizes of coal prepared from the Parkgate and Silkstone nuts with those for the "graded" sizes of coal (Tables LXXIII and LXXIV), it is seen that larger and harder cokes were made from the "through" sizes.

The size analyses of the cokes (Table LXXV) do not exhibit any marked differences dependent on the size of the coal used, the most noticeable result being the smaller amount of "useful coke" (*i.e.*, on 1½-in.) obtained when the maximum size of the crushed Parkgate and Silkstone slack was increased (cf. cokes Nos. 3F (I) and 3F (IV).

The results of the shatter tests (Table LXXVI) disclose an

TABLE LXXVI.—SHATTER INDICES OF COKES MADE FROM THROUGH SIZES OF COAL.

Coke No.	Coal Used.	Grading of Coal Charged.	Shatter Indices.			
			2-in.	1½-in.	1-in.	½-in.
3E (VII)	Parkgate and Silkstone nuts	Through ¼-in.; 60% through ⅛-in.	77·3	89·1	95·4	98·4
3E (VIII)		Through ⅛-in.	79·5	88·5	94·8	98·0
3E (VI)		Through 1/16-in.	71·6	88·3	96·5	98·6
3F (IV)	Parkgate and Silkstone slack	Through ½-in.; 80% through ¼-in.; 60% through ⅛-in.	77·6	88·4	95·1	98·0
3F (I)		Through ¼-in.; 60% through ⅛-in.	78·5	90·9	96·8	98·6
3F (II)		Through ⅛-in.	79·9	91·8	97·4	98·8
3G (I)	Wath Wood High Hazel and Barnsley slack	Through ¼-in.; 60% through ⅛-in.	78·3	88·2	93·8	96·9
3G (II)		Through ⅛-in.	71·1	87·4	95·0	96·9

abnormal relationship between the 2-in. and 1½-in. indices for cokes Nos. 3E (VI) and 3G (II). This can be ascribed to the prismatic shape of these cokes, as indicated by the small amounts of on 2-in. sizes (see Table LXXV). Considering only the 1½-in. indices, the results for the other cokes do not suggest that any advantage was gained by fine crushing of either the Parkgate and Silkstone nuts, or the Wath Wood, High Hazel and Barnsley slack. With the Parkgate and Silkstone slack, however, fine crushing produced rather a better result than coarse crushing. When the maximum size of this slack was raised from ¼-in. to ½-in., the coke was decidedly weaker.

The actual size analyses of the coals as charged to the ovens in these tests are recorded in Table LXXVII, together with summarised data for the size analyses and shatter indices of the cokes.

TABLE LXXVII.—COMPARISON OF COARSE AND FINE CRUSHING OF COAL.

Coke No.	Coal Used.		Size Analysis of Coal.					Size Analysis of Coke.		Shatter Indices.	
			Through								
			¼-in.	⅛-in.	1/20 in.	1/40 in.	1/120 in.	On 3-in.	On 1½-in.	2-in.	1½-in.
3E (VII)	Parkgate and Silkstone nuts	Coarse	98	60	15	12	7	33	89	77·3	89·1
3E (VIII)		Fine	100	100	70	42	17	40	88	79·5	88·5
3E (VI)		Very fine	100	100	93	52	19	18	90	71·6	88·3
3F (I)	Parkgate and Silkstone slack	Coarse	100	61	37	19	8	29	91	78·5	90·9
3F (II)		Fine	100	100	75	43	20	25	92	79·9	91·8
3G (I)	Wath Wood High Hazel and Barnsley slack	Coarse	100	54	24	11	6	40	88	78·3	88·2
3G (II)		Fine	100	100	73	41	17	17	86	71·1	87·4

Coarse crushing thus yielded about 60 per cent. and fine crushing about 100 per cent. of coal through $\frac{1}{8}$-in. size.

Considering the results as a whole, these series of tests suggest that, for certain coals, $\frac{1}{4}$-in. may be the critical maximum size for the production of the best coke. A reduction in the maximum size of the coal from $\frac{1}{4}$-in. to $\frac{1}{8}$-in. had but little effect on the coke, and further reduction to $\frac{1}{16}$-in. was without advantage. On the other hand, increasing the maximum size of the coal to $\frac{1}{2}$-in. caused a decrease in the amount of "useful coke" and a reduction in its hardness. It would seem desirable, therefore, to ensure the absence of over $\frac{1}{4}$-in. sizes in the crushed coal charged to the ovens rather than, as is customary, to attempt to increase the proportion of through $\frac{1}{8}$-in. sizes.

Size Analyses of Coals Charged in Practice.—We have obtained size analyses of many of the coals used for the production of the cokes we have tested. A number of these are recorded in Table LXXVIII. Some excellent cokes are made from coals containing a considerable proportion of over $\frac{1}{4}$-in. sizes, notably the two Welsh cokes Nos. 1 and 14 and the Durham coke No. 6. Amongst the Yorkshire and Derbyshire coals, however, it is rare to find more than 5 per cent. over $\frac{1}{4}$-in. in the crushed coal charged to the ovens.

Certain relatively poor caking coals of low swelling power yield cokes having a high percentage of enlarged pores, their structure being irregular. The compression of such coals increases their bulk density and generally causes the coke produced from them to be of more regular porous structure. It is probable, therefore, that a similar improvement could be effected in the quality of the coke produced from such relatively poor caking coals when, as in modern ovens, they are top-charged, if their bulk density could be increased. It might be possible to do this by so arranging the proportions of the different sizes of coal in the charge that the finer particles filled the voids between the larger.

Evans (*Journ. West of Scotland Iron and Steel Inst.*, 1925, 76) has recorded the results of blast-furnace tests on the North-East coast in which the coke consumption was reduced and the output of the furnace increased, the furnace working more regularly and with a reduced blast pressure, when the coal used for the manufacture of the coke was more finely crushed. We have no knowledge of the size analyses of the crushed coals used but, judging from our own results, we assume that the effect of the finer crushing was mainly to reduce the amount of over $\frac{1}{4}$-in. sizes.

Greenfield and Harrison (*Gas Journal*, special Number, Sept. 14th, 1928, 45) found that with a Durham coal crushed so that 80 per cent. passed through a $\frac{1}{8}$-in. screen and 98 per cent. through a $\frac{1}{2}$-in., the 2 per cent. oversize might consist of equal parts of coal and shale, the concentration of the shale in the oversize being due to its resistance to crushing. Braunholtz, Briscoe and Nave (*Fuel*, 1929, **9**, 419) have recorded the size analyses of a number of Durham coals as charged to the ovens, with the ash-contents of each size.

The larger sizes often contained the higher proportions of ash, presumably because of the presence of shale. For example:

Coal No.	Ash-contents.	
	⅛–¼-in. size.	¼–½-in. size.
12E	7·1	13·5
27	2·8	3·0
32E	7·9	15·7
33	11·2	10·4
45	5·0	16·2

TABLE LXXVIII.—SIZE ANALYSIS OF CRUSHED COALS AS CHARGED IN DIFFERENT DISTRICTS.

District.	Coke No.	Per cent. of Coal through						
		½-in.	¼-in.	⅛-in	⅒-in.	$\frac{1}{20}$-in.	$\frac{1}{30}$-in.	$\frac{1}{120}$-in.
South Wales	1	100·0	83·8	60·5	53·2	36·7	24·5	8·0
	14	100·0	88·8	70·2	63·7	41·3	22·4	8·5
	39	100·0	92·1	74·3	65·8	43·4	26·3	9·2
Durham	2	95·6	83·1	64·8	58·1	36·1	22·3	9·3
	W	100·0	100·0	—	77·8	56·4	36·4	16·2
	6	97·8	84·9	—	68·8	45·1	27·5	10·5
	F	100·0	92·8	—	77·3	55·5	34·1	11·0
	30A	100·0	100·0	—	91·2	72·7	50·5	22·9
	B	100·0	100·0	—	94·6	79·0	54·8	24·1
South Yorks.	18A–G	100·0	97·4	85·0	75·0	46·7	27·1	12·0
	18H–K	100·0	99·0	93·8	87·8	58·8	36·5	15·3
	46	99·7	91·2	74·2	73·7	39·6	26·6	11·0
	37	100·0	99·3	98·4	73·9	46·3	14·5	9·5
	17A, B	100·0	100·0	—	80·8	53·2	32·8	15·0
	C	100·0	100·0	—	72·2	47·6	31·6	14·5
	33	100·0	100·0	—	53·6	28·0	15·8	7·4
	35	100·0	93·1	—	76·2	53·8	35·6	15·5
	H.S.	100·0	100·0	—	95·1	59·1	38·7	16·5
	38A	99·2	89·6	—	57·7	35·5	21·3	8·4
	49	100·0	96·9	84·5	—	66·3	41·0	—
Derbyshire	28A–E	100·0	100·0	—	84·4	59·4	37·8	15·2
	22F	100·0	95·7	83·0	72·8	46·9	27·1	10·7
	45	100·0	99·5	95·3	91·9	73·4	49·1	21·4
Cumberland	W	100·0	100·0	—	69·0	42·6	25·4	10·1
	20	99·5	96·6	82·7	76·6	49·5	32·0	16·0
	21	97·2	93·3	81·0	74·3	52·2	35·3	17·2
Lancashire	16	100·0	98·4	91·5	84·5	60·0	39·0	17·2
Staffordshire	S	100·0	99·4	—	65·8	38·0	24·8	2·5
Scotland	B	100·0	97·5	—	90·1	73·8	52·4	19·6
Germany	B	100·0	98·8	—	70·6	43·3	19·7	3·1

Pieces of shale of ¼–½ in. size in the coal charge form points of weakness in the coke, acting as *loci* for contraction and causing the formation of fissures. This is illustrated by the coke sections reproduced on Plate XXXVIII, the fissures radiating from pieces of shale in the cokes being clearly marked.

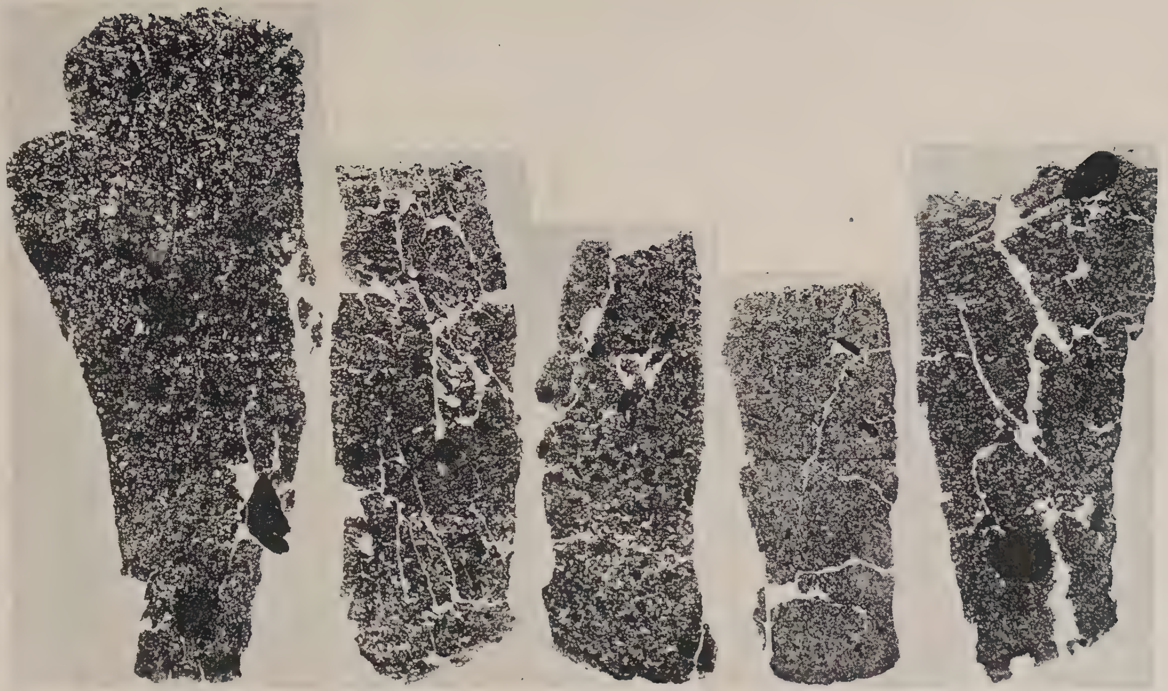


PLATE XXXVIII.—Effect of Pieces of Shale in Initiating Fractures in Coke.
(The shale is seen as dark particles. The size of pyritic particles is exaggerated by an iron stain.)

[*To face p.* 200.

These observations provide a basis for the belief in the efficacy of fine grinding of the coal used for the manufacture of coke, but suggest that the value of fine grinding lies in the removal of the larger pieces (over $\frac{1}{4}$-in. in size) of coal and, more particularly, of shale which by their presence reduce the hardness of the coke.

The Influence of the Size of the Coal on the Density and Porosity of the Coke

Determinations of the real and apparent densities and of the total and apparent porosities of the cokes made from "graded" and "through" sizes of coal (series 3E, 3F and 3G) are recorded in Table LXXIX.

Table LXXIX.—The Influence of the Size of the Coal on the Density and Porosity of the Coke.

Coke No.	Size of Coal (inch).	Apparent Density.	Apparent Porosity (per cent.).	Total Porosity (per cent.).	Real Density (ash-free).
3E (I)	$1-\frac{1}{2}$	0·98	34·1	51·5	1·93
3E (II)	$\frac{1}{2}-\frac{3}{8}$	0·96	36·7	51·5	1·88
3E (III)	$\frac{3}{8}-\frac{1}{4}$	0·98	41·9	51·5	1·94
3E (IV)	$\frac{1}{4}-\frac{1}{8}$	0·89	44·2	54·8	1·90
3E (V)	$\frac{1}{8}-\frac{1}{16}$	0·81	46·6	58·2	1·90
3E (VII)	Through $\frac{1}{4}$	0·88	43·0	54·9	1·91
3E (VIII)	Through $\frac{1}{8}$	1·02	30·4	47·4	1·87
3E (VI)	Through $\frac{1}{16}$	0·86	41·1	55·2	1·88
3F (IV)	Through $\frac{1}{2}$	0·93	44·8	53·0	1·90
3F (I)	Through $\frac{1}{4}$	0·89	35·4	54·6	1·88
3F (II)	Through $\frac{1}{8}$	0·84	43·8	56·8	1·88
3G (I)	Through $\frac{1}{4}$	0·96	35·9	46·4	1·72
3G (II)	Through $\frac{1}{8}$	0·88	40·9	51·6	1·75

Note.—The 3E series of cokes were made from good caking Parkgate and Silkstone nuts, the 3F series from Parkgate and Silkstone slack and the 3G series from poor caking Wath Wood, High Hazel and Barnsley slack.

The cokes made from the graded sizes of coal do not differ much as regards their apparent density and total porosity until the size of the coal is less than $\frac{1}{4}$-in. The apparent density then falls and the total porosity rises as the size of the coal or, rather, as the size of the voids, is decreased, no doubt because the escape of gases is then restricted. This effect is noticeable also with the cokes made from the "through" sizes of coal, though the results for coke No. 3E(VIII) are anomalous.

The apparent porosity of the coke increases regularly with the decrease in the size of the coal when the size is graded, probably because of an increasing tendency for the formation of closed pores within the individual lumps of coal rather than at the interfaces.

The real density of the coke substance in all the cokes made from the good caking Parkgate and Silkstone nuts or slack is high, whilst

UNIVERSITY
COLLEGE
LIBRARY
NOTTINGHAM

that in the cokes made from the poor caking slack is low. Although several factors may affect the real density, these determinations afford an example of the dependence of the real density of the coke material on the constitution of the coal used.

THE INFLUENCE OF THE SIZE OF THE COAL ON THE REACTIVITY OF THE COKE

Complete records of furnace tests are not yet available for all the cokes made from graded and through sizes of coal, but some are given in Table LXXX.

TABLE LXXX.—THE INFLUENCE OF THE SIZE OF THE COAL ON THE REACTIVITY OF THE COKE.

Coke No.	Size of Coal (inch).	Reactivity with Oxygen (distance, in inches, for disappearance of oxygen).		Reactivity with Carbon Dioxide (distance, in inches, for 20% carbon monoxide).		Temperature of Combustion, °C.	
		2nd Set.	1st Set.	2nd Set.	1st Set.	Maximum.	Average.
3E (I)	$1-\frac{1}{2}$	5	4	12	11	1665	1545
3E (II)	$\frac{1}{2}-\frac{3}{8}$	4	4	11	12	1660	1535
3E (V)	$\frac{1}{8}-\frac{1}{16}$	6	4	>12	12	1680	1555
3E (VIII)	Through $\frac{1}{8}$	5	5	10	10	1720	1565
3E (VI)	Through $\frac{1}{16}$	5	5	>12	10	1700	1565
3F (I)	Through $\frac{1}{4}$	5	6	9	10	1710	1565
3F (II)	Through $\frac{1}{8}$	4	4	9	9	1750	1540
3G (I)	Through $\frac{1}{4}$	4	4	9	10	1690	1565
3D	(Beehive coke)	6	6	>12	>12	1790	1600

Note.—Series 3E made from Parkgate and Silkstone nuts; series 3F from Parkgate and Silkstone slack; 3G from Wath Wood, High Hazel and Barnsley slack; 3D from Parkgate and Silkstone pearls in a beehive oven.

The general conclusion to be drawn from this limited number of tests is that cokes made from the finer sizes of coal produce the higher maximum and average temperatures on combustion. Within the limits of grinding in practice, however, it is doubtful whether "fine" as compared with "coarse" grinding would affect the quality of the coke in this respect.

SUMMARY

The most important effect of the size of the coal used for the manufacture of metallurgical coke on the quality of the coke produced is on its size and hardness. Very fine grinding (all through $\frac{1}{8}$-in. or $\frac{1}{16}$-in.) has not been found to have a material advantage over coarse grinding (60 per cent. through $\frac{1}{8}$-in.), but the presence in the coal charge of pieces greater than $\frac{1}{4}$-in. seems to be detrimental to the quality of the coke. From the results obtained with two different types of Yorkshire slacks, it would seem preferable to aim to exclude pieces of coal (and shale) greater than $\frac{1}{4}$-in. from the charge rather than to strive to obtain a high percentage through $\frac{1}{8}$-in.

CHAPTER IV

THE INFLUENCE OF THE METHOD OF CHARGING THE OVEN

It has generally been considered that of the two methods of charging a coke oven, by loading the coal by gravity from hoppers through three or four openings in the top of the oven (" top-charging " or " loose-charging "), or by first compressing it into a cake and loading it to the oven from one end (" cake-charging " or " compressed-charging "), the latter enables a better coke to be made from poor caking coals and increases the output per oven.

Byrom and Christopher (" Modern Coking Practice," p. 87, London, 1921) record that the density of a crushed coal before it was compressed into a cake was 46·1 lb. per cu. ft., whilst after compression the density at the middle of the cake was 56·8 lb. per cu. ft., an increase of 23 per cent. On the other hand, it is common to leave a clearance of one inch between the sides of the cake and the walls of the oven, thereby reducing the effective width of the oven by two inches, or 10 per cent. on a 20-in. oven. The ends of the cake also usually slope downwards to the oven doors. On the whole, it is doubtful whether the increased weight of charge to an oven obtained by compression often exceeds 10 per cent. Since the coking time is usually extended nearly in proportion, the net increase in throughput is small.

A compressed cake of coal has to pass on the bottom plate of the cake box to the oven without breaking. To do so it must be sufficiently firm and the ratio of the height of the cake to its width must not exceed a maximum, usually taken at 6 to 1. In older coke-oven practice, with a 21-in. oven and a 19-in. cake, the maximum height of the cake was about 9½ ft. In more recent practice, with ovens 18 inches or less in width, a 16-in. cake, for example, would have a maximum height of 8 ft. In modern practice, the width of the oven may be as little as 13¾ inches and the use of compressed charges is, in consequence, precluded. It has therefore become important to determine what influence, if any, the method of charging the oven has on the quality of the coke produced.

On changing over from, say, a 21-in. cake-charged to an 18-in. top-charged oven, the quality of the coke might be affected by either the method of charging or the difference in the rate of heating the charge due to the difference in the widths of the ovens. In order that any effect of the rate of heating might be eliminated, we have carried out tests, on the same coals, with ovens of the same width, varying only the method of charging.

THE INFLUENCE ON THE SIZE OF THE COKE

Some results illustrating the influence of the method of charging the oven on the size of the coke have been recorded in Table VII (p. 24). More complete data are given in Table LXXXI.

TABLE LXXXI.—THE INFLUENCE OF THE METHOD OF CHARGING THE OVEN ON THE SIZE OF THE COKE.

Coke No.	Origin.	Coal Used.	Method of Charging.	Width of Oven (in.).	Coking Time (hr.).	Size Analysis of Coke.*				
						On 4-in.	On 3-in.	On 2-in.	On 1½-in.	On 1-in.
17A	S. Yorks.	Parkgate 53% Silkstone 27 Barnsley 20	Top	20	30	59·8	79·7	90·9	94·6	97·1
17B			Cake	20	34	41·8	64·7	83·3	91·6	97·2
18E	S. Yorks.	Thorncliffe 59% Flockton 41	Top	20	32½	43·8	75·2	92·9	96·0	98·1
18C			Cake	20	36	28·6	51·6	81·3	92·6	97·5
18F	S. Yorks.	Thorncliffe 59% Flockton 41	Top	18	19¼	3·1	23·4	63·8	83·4	94·4
18G			Cake	18	21½	0·7	19·0	59·2	86·5	97·7
29B	S. Yorks.	Parkgate 67% Silkstone 33	Top	21	22½	13·7	42·0	78·5	89·0	95·2
29A			Cake	21	25¾	14·6	35·4	75·1	85·9	94·6
20A	Cumberland	Six-Quarter 70% Little Main 17 Four Foot 13	Top	20½	24	50·7	70·8	89·6	94·6	97·0
20B			Cake	20½	28	52·0	73·8	88·1	94·0	97·1
21A	Cumberland	Six Quarter 75% Main Band 25	Top	20½	25	19·7	48·2	73·6	87·1	94·0
21B			Cake	20½	28	13·1	39·7	67·3	85·1	94·5

* As received at the laboratory.

In general, the coke from the top-charged oven has a better size analysis than that from the cake-charged, cokes Nos. 20A and 20B being exceptional. Four out of the six "cake-charged" cokes, however, yielded the better results at the 1-in. screen, an observation, confirmed by the results of shatter testing and abrasion testing, implying that the "cake-charged" cokes are rather less readily abraded than the "top-charged" and produce rather less breeze.

It will be noted that the coking times for the cake-charged ovens were from 2¼ to 4 hours longer than for the top-charged, the average for the six pairs of tests being about 11½ per cent.

THE INFLUENCE ON THE HARDNESS OF THE COKE

The influence of the method of charging the oven on the hardness of the coke is illustrated in Table LXXXII.

The hardness of the "top-charged" coke is always greater than that of the "cake-charged." The ½-in. indices, which give a rough measure of the abradability (abrasion hardness) of the cakes, supports the suggestion founded on the results of the size analyses (*q.v.*) that the "cake-charged" cokes are slightly less readily abraded than the "top-charged." For two of the pairs of cokes, abrasion tests were made, with the following results :

Coke No.	Abrasion Indices.	
	On 1½-in.	Through 1/16-in.
17A (top-charged) . . .	98·2	1·2
17B (cake-charged) . .	98·0	0·4
18E (top-charged) . . .	92·9	1·1
18C (cake-charged) . . .	93·8	0·7

TABLE LXXXII.—THE INFLUENCE OF THE METHOD OF CHARGING THE OVEN ON THE HARDNESS OF THE COKE.

Coke No. (see Table LXXXI for description).	Method of Charging.	Shatter Indices.			
		2-in.	1½-in.	1-in.	½-in.
17A	Top	81·6	90·0	94·9	97·9
17B	Cake	65·3	81·6	92·3	98·3
18E	Top	75·2	83·9	92·3	97·7
18C	Cake	61·6	77·4	89·9	97·6
18F*	Top	78·5	88·6	94·7	98·2
18G*	Cake	60·7	79·2	92·6	98·2
29B	Top	74·1	86·7	94·1	97·4
29A	Cake	64·5	79·0	91·0	97·6
20A	Top	74·8	87·7	93·5	97·7
20B	Cake	66·9	79·7	90·6	97·2
21A	Top	60·8	76·6	89·6	96·8
21B	Cake	52·7	74·9	88·2	96·9

* Shatter index the mean of two tests only.

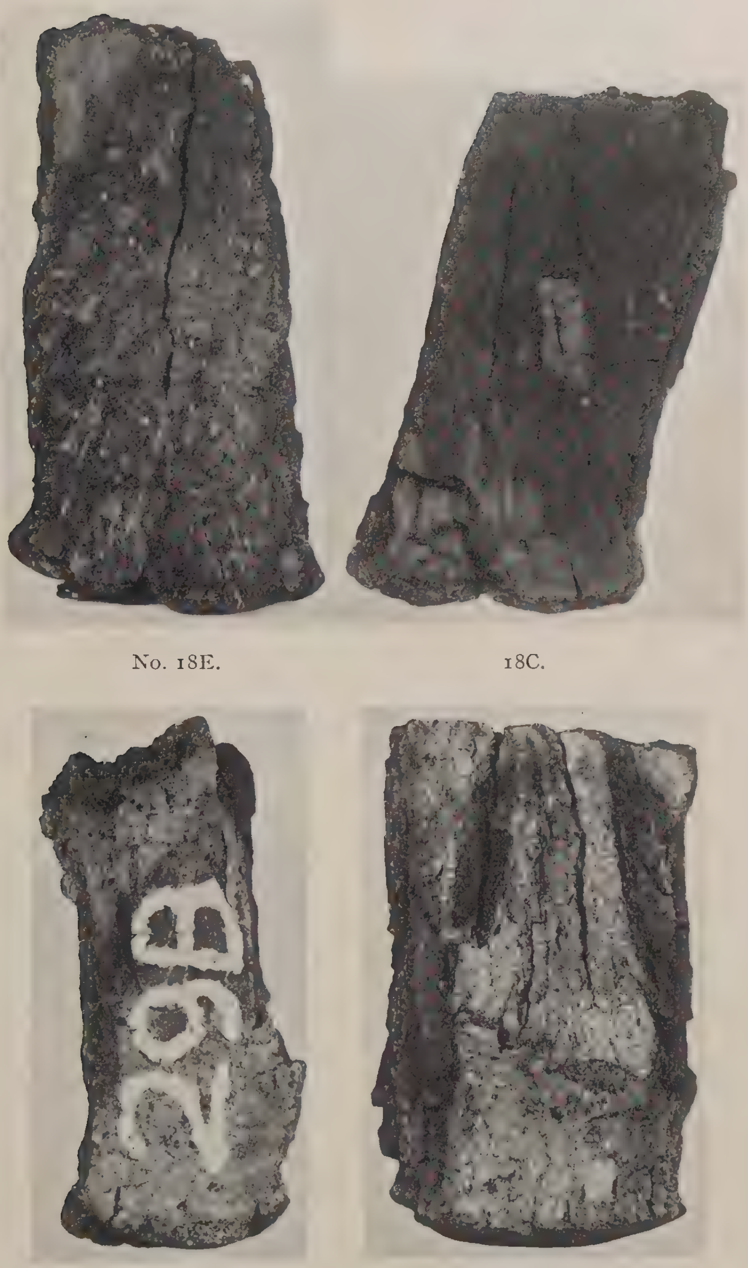
THE INFLUENCE ON THE DENSITY AND POROSITY OF THE COKE

The influence of the method of charging the oven on the density and porosity of the coke is illustrated by the determinations recorded in Table LXXXIII.

With one exception (coke No. 21A), the " top-charged " cokes have a lower apparent density and a higher porosity than the corresponding " cake-charged." This is a direct consequence of the smaller bulk-density of the coal as charged. Bulk density determinations of the shattered cokes are not available, but it is clear that a skip load of " cake-charged " coke would weigh more than a skip load of " top-charged " coke.

THE INFLUENCE ON THE STRUCTURE OF THE COKE

Plates XXXIX to XLII illustrate the influence of the method of charging the oven on the structure of the cokes, so far as their external appearance and the appearance of sections are concerned.



Top-charge. Cake-charge.

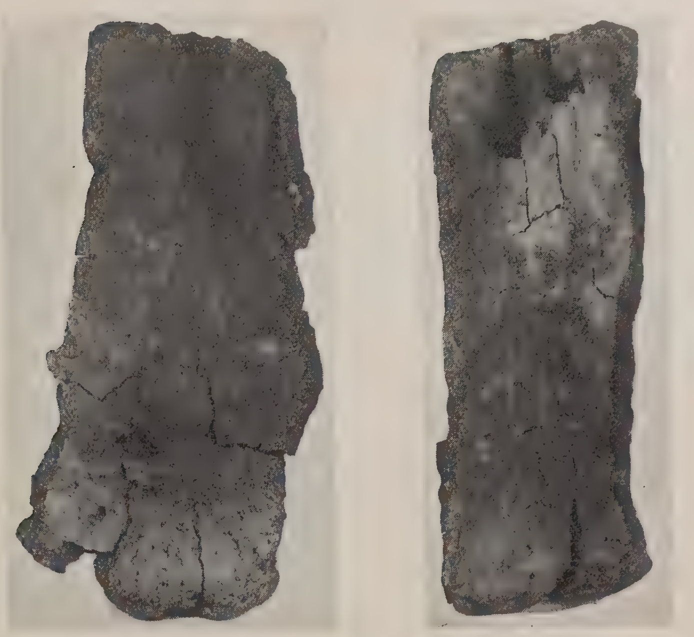
No. 18E. 18C.

No. 29B. 29A.

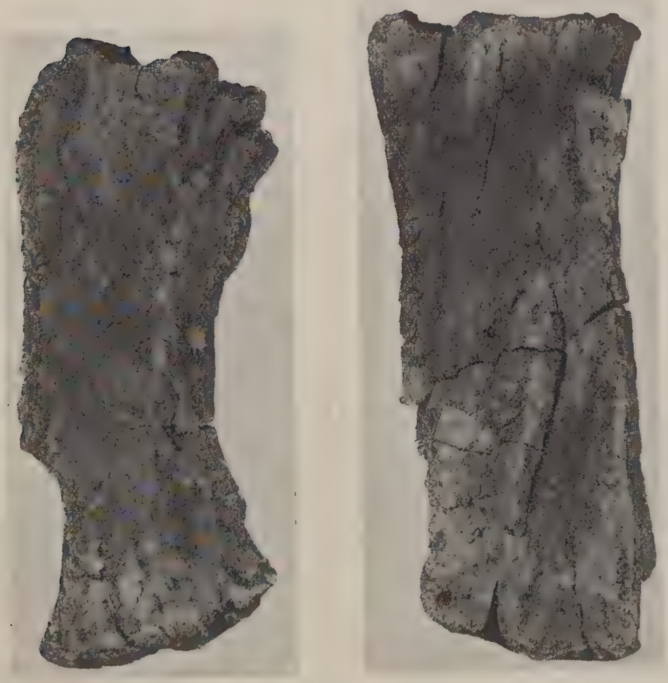
PLATE XXXIX.—Comparison of Shape of Coke made from Top-charged and Cake-charged Coal (South Yorkshire).

[*To face p.* 206.

Top-charge. Cake-charge.



No. 20A. 20B.



No. 21A. 21B.

PLATE XL.—Comparison of Shape of Coke made from Top-charged and Cake-charged Coal (Cumberland).

[*To face p.* 206.

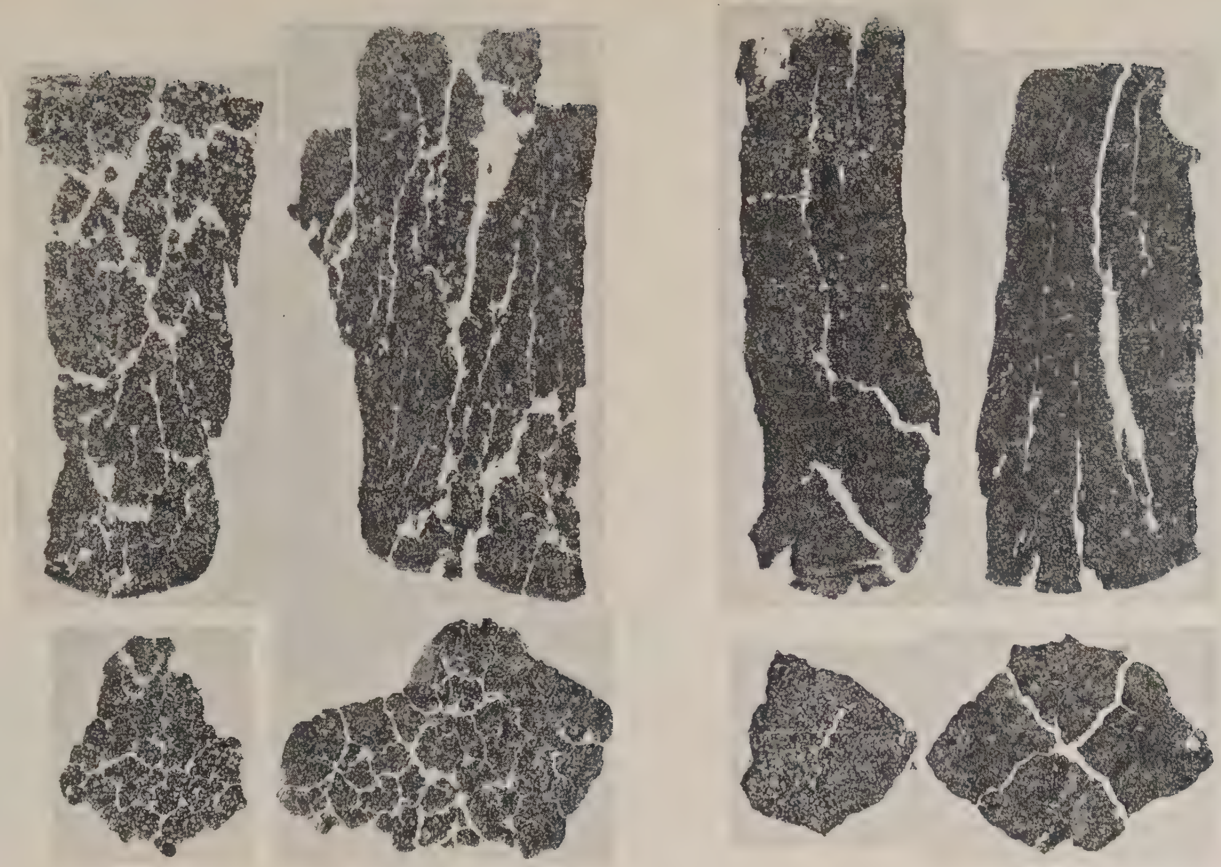

Top-charge.
Cake-charge.
Top-charge.
Cake-charge.
No. 18E.
18C.
29B.
29A.

PLATE XLI.—Comparison of Fracturing of Cokes made from Top-charged and Cake-charged Coal (South Yorkshire).

[*To face p.* 206.

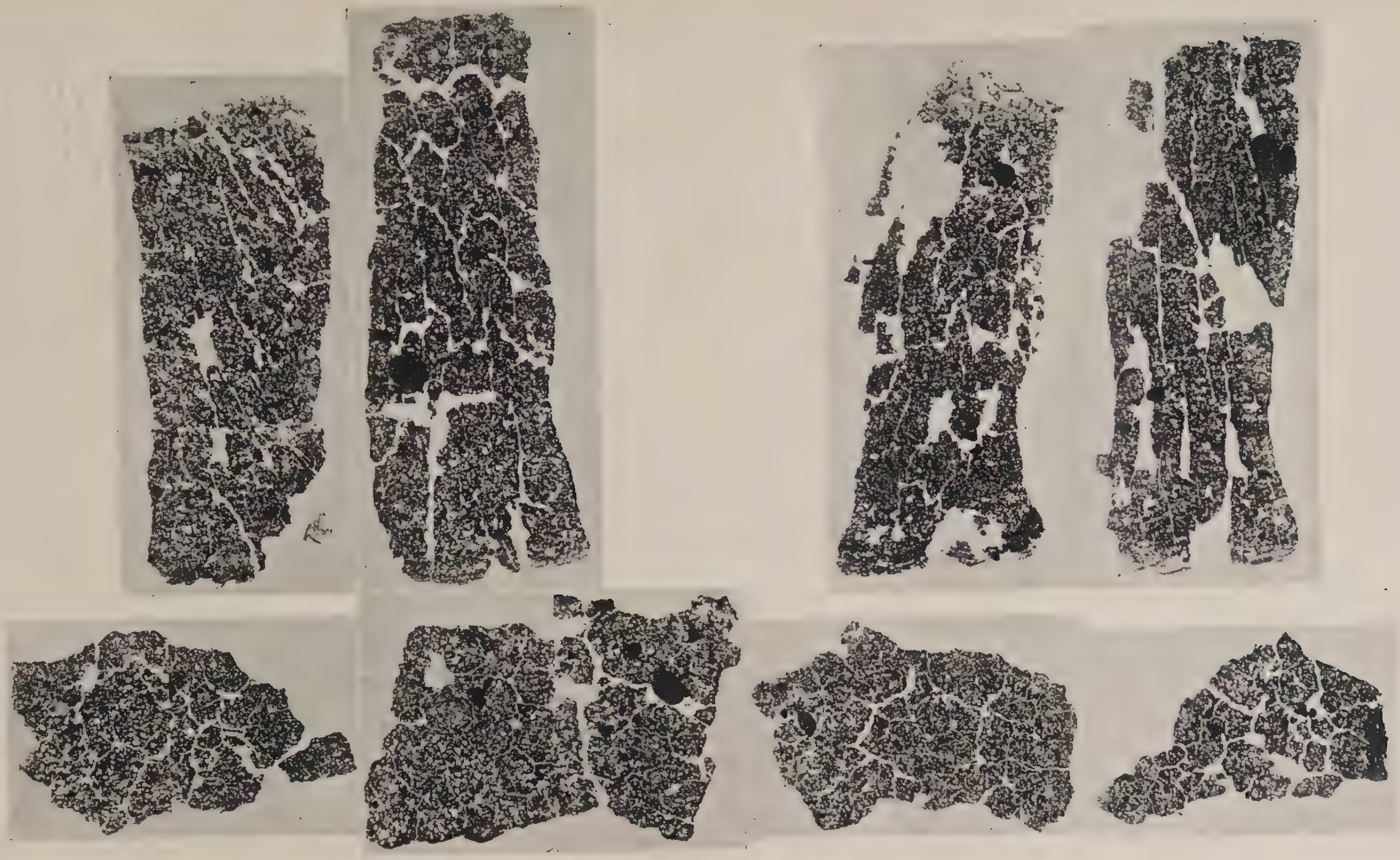

Top-charge.
Cake-charge.
Top-charge.
Cake-charge.
No. 20A.
20B.
21A.
21B.

Plate XLII.—Comparison of Fracturing of Cokes made from Top-charged and Cake-charged Coal (Cumberland).

[To face p. 206.

Table LXXXIII.—The Influence of the Method of Charging the Oven on the Density and Porosity of the Coke.

Coke No. (see Table LXXXI for description).	Method of Charging.	Density.		Percentage Porosity		Real Density (on ash-free basis)
		Apparent.	Real.	Open Pores.	Total Pores	
17A	Top	0·94	1·94	45·1	51·5	1·88
17B	Cake	1·04	1·92	37·8	45·8	1·85
18E	Top	0·84	1·84	45·8	54·4	1·76
18C	Cake	0·93	1·87	42·9	50·3	1·81
18F	Top	0·83	1·87	46·3	55·6	1·80
18G	Cake	0·92	1·87	28·5	50·9	1·80
29B	Top	0·85	1·86	45·3	54·2	1·80
29A	Cake	1·02	1·87	34·8	45·4	1·81
20A	Top	0·87	1·95	39·2	55·5	1·90
20B	Cake	0·93	1·89	34·9	50·8	1·83
21A	Top	0·95	1·97	36·8	51·8	1·91
21B	Cake	0·94	1·92	36·7	51·0	1·86

The shapes of the cokes are, in general, more regularly rectangular when they have been made from cake-charged coal (Plates XXXIX and XL). This better appearance and the greater bulk-density (suggesting greater strength) of the "cake-charged" cokes no doubt accounts for the preference often given to cake-charging. The photographs of the cross-sections on Plates XLI and XLII show, however, that the "top-charged" are less fissured than the corresponding "cake-charged" cokes, just as they are harder and have a better size analysis.

The Influence on the Reactivity of the Coke

It has been shown previously (Part I, Chapter VIII) that differences between the specific reactivities of a number of cokes are small compared with the differences in reactivity between various sizes of the same coke. Comparison of the specific reactivity of "top-charged" and "cake-charged" cokes must therefore take into account their differences in size and hardness. The specific reactivity and combustion temperatures of a number of "top-charged" and "cake-charged" cokes are recorded in Table LXXXIV.

No general deduction can be drawn from these results. With two out of the three pairs of Yorkshire cokes (the first three pairs in the table), the "cake-charged" coke yields the higher maximum temperature of combustion and the higher average fuel-bed temperature, but with the Cumberland cokes (the last two pairs in the table) the "top-charged" are preferable in these respects. If the method of charging had but little effect on the size and hardness

TABLE LXXXIV.—THE INFLUENCE OF THE METHOD OF CHARGING THE OVEN ON THE REACTIVITY OF THE COKE.

Coke No. (see Table LXXXI for description).	Method of Charging.	Oxygen Disappears (inches).		Carbon Monoxide, 20% (inches).		Maximum Temp. °C.		Average Temp. °C.
		2nd Set.	1st Set.	2nd Set.	1st Set.	2nd Set.	1st Set.	2nd Set.
17A	Top	6	4	12	10	1650	1650	1545
17B	Cake	4	5	10	9	1700	1700	1580
18E	Top	5	5	11	11	1630	1690	1485
18C	Cake	4	6	12	9	1675	1700	1505
29B	Top	4	6	11	11	1670	1650	1540
29A	Cake	4	3	12	11	1670	1600	1510
20A	Top	6	4	12	12	1775	1670	1595
20B	Cake	4	6	12	12	1710	1680	1590
21A	Top	5	6	12	11	1790	1725	1570
21B	Cake	6	6	12	11	1700	1650	1555

of the coke (as with some Durham coals), it is probable that, in some instances, better blast-furnace and cupola cokes would be produced by cake charging than by top charging.

A FURTHER COMPARISON OF "TOP-CHARGED" AND "CAKE-CHARGED" COKES

Similar results to those here recorded have been obtained by the Northern Coke Research Committee and published in *Fuel*, 1929, **8**, 421. Their records are reproduced in Table LXXXV.

TABLE LXXXV.—THE INFLUENCE OF THE METHOD OF CHARGING THE OVEN ON THE QUALITY OF THE COKE (NORTHERN COKE RESEARCH COMMITTEE).

Coke No. (Northern Coke Research Committee).	Origin.	Method of Charging.	Shatter Index.		Apparent Density.	Percentage Porosity.
			2-in.	1½-in.		
12A	Durham	Top	65	81	0·94	52·7
12B		Cake	58	77	1·10	42·5
32A	Durham	Top	73	85	0·94	50·1
32B		Cake	66	80	1·05	45·8
32E	Durham	Top	74	85	1·04	47·2
32F		Cake	67	82	1·10	44·9
32I	Durham	Top	79	86	0·95	52·6
32K		Cake	58	69	1·06	45·2

SUMMARY

When a coal is top-charged to an oven, the coke produced is often less regular in shape and generally of not such a good appearance as when the coal has been cake-charged. In general, however, the "top-charged" coke has the better size analysis and is harder, because less fissured. For blast-furnace coke it would seem preferable always to adopt top-charging rather than cake-charging of the coal.

With Derbyshire coals (for which, however, no directly comparable tests in the same ovens have as yet been made) a larger percentage of "useful coke," which is also harder, is produced by top-charging the coal to fast-coking ovens than by cake-charging it to slowly-coking ovens.

With such coals as are found with cake-charging to yield brittle, very dense cokes (apparent specific gravity greater than 1·0) top-charging effects a marked improvement. This is exemplified by tests with blends of a Saar coking coal with low-temperature coke breeze. The blend yielded a much superior coke when top-charged than when cake-charged.

CHAPTER V

THE INFLUENCE OF MOISTURE

UNTIL recently, but little of the coal charged to coke ovens was unwashed. Washed coal may contain up to 20 per cent. of water, reduced by natural drainage in hoppers to between 10 and 15 per cent., dependent on the size of the coal. By means of dewatering screens, the moisture-content of washed coal can be reduced rapidly to 10 or 12 per cent.; by means of centrifuges it can be reduced still further; and by dryers the surplus moisture can be removed completely (see R. A. Mott, " The Dewatering and Drying of Coal," *Trans. World Power Conference, London*, 1928, Vol. I). When coal is cake-charged to the ovens, the presence of 8 to 10 per cent. of moisture is usually considered essential for the formation of a firm cake.

In American coke-oven practice, crushed run-of-mine coal is commonly used and experience with this unwashed coal shows that it cokes more rapidly than wet coal. With a 10-ton charge containing 10 per cent. of water, 1 ton of water must be evaporated in the oven, the heat absorbed being about one-quarter of that passing to the oven from the flues. With a wide (21-in.) oven that cokes a coal containing 10 per cent. of moisture in 32 hours, a reduction of 7 per cent. in the moisture-content would shorten the coking time by about 6 hours. With a modern 18-in. oven, coking in about 18 hours, the removal of 10 per cent. of moisture accounts for about 3 hours of the coking time.

The two important questions with regard to the moisture in coking slacks are: (1) can the moisture be removed more cheaply and efficiently outside the oven; and (2) does the reduction of the moisture-content materially affect the coking process and the quality of the coke.

For the evaporation of water in coal charged to the oven, heat must be expended. The evaporated water must be condensed, additional cooling water being required. The contact of the condensed liquor with the tar removes some phenols, causing some difficulty in the final disposal of the effluent. In the indirect and semi-direct processes for ammonia recovery, the condensed liquor has to be reheated to recover the ammonia. On the other hand, there are some advantages in a high moisture-content of the coal as regards a reduction of smoke nuisance during the top charging of ovens, a reduction in the formation of retort carbon and an avoidance of the blocking of ascension pipes and the thickening of tar, such as may occur if fine dry coal is carried over with the gas.

If the water can be removed from the coal at a low cost before it is charged to the ovens, it would seem on the whole preferable to do so. For though the actual cost of removing the water from the coal in the ovens is no doubt very low, since the surplus gas used for this purpose cannot be valued highly, a reduction in the coking time of from 10 to 20 per cent. may be an important economic advantage, provided that the quality of the coke does not suffer through the rapid heating.

Durham coals and low-volatile Westphalian coals can be successfully coked with fast rates of heating, and the dry coals can be coked in 14-in. silica ovens. With most high-volatile Yorkshire coals, however, a fast rate of heating tends to produce an excessive amount of spongy coke. With a 14-in. silica oven, a wet Yorkshire coking coal produces a better coke than a dry, and even in fast-coking ovens of 18 in. width too great a reduction in the moisture-content of the coal would tend to impair the size and hardness of the coke (*see* Part II, Chapter VI).

We have not as yet made any systematic experiments on the influence of moisture in coking practice. The results of two trials may be recorded here, though they are not entirely satisfactory, for a reason which will appear.

A charge of washed coal, containing 13 per cent. of moisture, was top charged to a 20-in. oven. It was coked in 36 hours. A second charge of the same coal was dried by the direct application of heat in a waste-heat dryer, the moisture being reduced to between 2 and 3 per cent., and stored in bags (whilst still at a temperature of 60° C.) until a suitable opportunity for coking it should arise. This opportunity unfortunately did not occur until 25 days later. The dried coal (which now contained less than 1 per cent. of moisture) was top-charged to a similar oven to that used for the wet coal. It was coked in 26½ hours. The average size analyses and shatter indices of the two cokes are recorded in Table LXXXVI.

TABLE LXXXVI.—COMPARISON OF COKES MADE FROM WET AND DRIED COAL.

Coke No.	Moisture in Coal Charged (per cent.).	Coking Time (hr.).	Size Analysis of Coke (per cent.).					Shatter Indices.	
			On 4-in.	On 3-in.	On 2-in.	On 1½-in.	On 1-in.	2-in.	1½-in.
26B	13·0	36	42	67	85	92	96	64	76
26A	1·0	26½	51	69	79	86	92	66	71

The coke made from the wet coal (26B) was of a good grey colour, but that made from the dried coal (26A) was dull in appearance, irregular in structure and deeply fissured. Although the coke from the dried coal had large and strong cauliflower ends (so that it compared favourably with the coke from the wet coal as regards the amount of 4-in. coke and the 2-in. shatter index), it formed much breeze. This inferior quality of the coke from the dried coal cannot, however, be ascribed solely, if at all, to the removal of moisture, for the dried coal would have become oxidised during its prolonged storage. The tests are of interest mainly in showing a decrease of 9½ hours in the coking time due to reduction of 12 per cent. in the moisture-content of the coal.

CHAPTER VI

THE INFLUENCE OF THE RATE OF HEATING THE OVEN

The rate at which heat is transmitted to a charge of coal in an oven is affected by several factors, for example: (1) by the width of the oven; (2) by the flue temperature; (3) by the character of the blend composing the coal charge; and (4) by the moisture-content of the charge. The rate of transmission of heat is different over different temperature ranges and in different zones of the oven. The most important temperature range is that over which the coal is plastic, and an average rate of heating for the oven can be assumed from measurements taken at one-quarter width.

Average Rates of Heating

The plastic range for all caking coals lies between 300° and 600° C., the exact temperature range depending on the rate of heating. In Table LXXXVII, the times taken for coal to pass through the range 300–600° C. in ovens of different widths are given, the values being taken from curves showing the rise in temperature at different zones in the ovens throughout the coking period.

Table LXXXVII.—Rates of Heating in Coke Ovens.

Width of Oven (inches).	Coking Time (hours).	Time (in hours) for rise from 300° to 600° C.		Authority.
		At ¼-width.	At centre.	
19½	30	4	3	Hilgenstock
20	32	—	3	Bell
20	28	5	3½	Cooper
20	28	5¾	4	
20	30	—	3½	Simmersbach
Average for 20-in. ovens coking in 28 to 32 hours		4·9	3·4	
17	16	3	3½	Porter
17	16	—	2½	
16	17	—	2	Bury
Average for 16–17-in. ovens coking in 16–17 hours . . .		3	2·7	
14	12	1¼	1	Midland Coke Research Committee
14	10	2¾	2	
Average for 14-in. ovens coking in 10–12 hours .		2	1½	

The average rates of heating therefore are, approximately :—

Width of Oven (inches).	Coking Time (hours).	Rate of Heating, °C. per min.		Rate of Heating (inches coked per hour).
		At ¼-width.	At centre.	
20	30	1·0	1·5	0·7
17	16	1·7	1·9	1·1
14	11	2·5	3·3	1·3

The highest rate of heating observed has been 5° C. per minute at the centre of a 14-in. oven. The rate of heating is sometimes expressed, as shown, in "inches of coal coked per hour." In the absence of temperature measurements, this is a convenient mode of expression.

We have carried out a number of tests in which the same quality of coal has been charged to ovens of different widths, with different coking times. Until recently, ovens of 16-in. and 18-in. width have not been available for test purposes in the Yorkshire area, so that most of our data relate to wide (20- or 21-in.) and very narrow (14-in.) ovens. The coal has been top-charged in each instance.

The Influence on the Size of the Coke

The influence of different rates of heating on the size of the coke can be gauged from the records given in Table LXXXVIII. In each group made from the same coal, the cokes are arranged in order according to the rate of heating of the oven, the coke made at the slowest rate of heating being listed first.

All the cokes bearing the number 29 were made at the same coke-oven plant and they were all handled in the same way, whether they came from 21-in. or 14-in. ovens. Their size analyses are therefore strictly comparable. In the other series of tests, the ovens of different widths were at different plants and the handling to which the cokes were subjected before the size analyses were made was not necessarily the same.

Considering first the No. 29 series of cokes, it appears that, whether the charge is a mixture of good (Parkgate and Silkstone) or of poor (Wath Wood and Swallow Wood) caking coals, or is a blend of the two mixtures, the percentages of on 4-in. and on 3-in. sizes is greater with the ovens having the slower rates of heating. The blend of a good caking coal with anthracite duff yielded a larger size of coke with the slower rates of heating, as did, though not to a marked degree, the blend with low-temperature coke breeze. With this latter blend, the rates of heating were rapid in both the 21-in. and the 14-in. oven, no doubt because the low-temperature coke breeze reduced the resistance of the plastic layer and allowed hot gases to pass through it. This effect was more pronounced with the wider oven and the coking time with this blend (14½ hours) is one of the lowest ever observed for the coking of a wet charge in a 21-in. oven.

TABLE LXXXVIII.—SIZE ANALYSES OF COKES FROM THE SAME COALS COKED IN OVENS OF DIFFERENT WIDTHS.

Coke No.	Coal Used.	Width of Oven (inches).	Coking Time (hours).	Rate of Coking (inches per hour).	Size Analysis.				
					On 4-in.	On 3-in.	On 2-in.	On 1½-in.	On 1-in.
29B	Parkgate and Silkstone (S. Yorks.)	21	22½	0·95	13·7	42·0	78·5	89·0	95·2
29C		14	12	1·17	6·5	31·9	82·2	93·5	97·3
29D	Wath Wood and Swallow Wood (S. Yorks.)	21	22½	0·95	14·4	36·6	71·1	84·0	93·4
29E		14	13	1·08	3·1	18·5	62·4	80·3	91·7
29F	80% Parkgate and Silkstone 20% Wath Wood and Swallow Wood	21	24	0·87	17·7	38·4	71·8	85·0	94·4
29G		14	12¼	1·12	1·4	11·9	58·1	81·2	93·1
29K	80% Parkgate and Silkstone 20% low-temp. coke breeze	14	10	1·40	39·7	64·1	83·0	89·5	93·3
29J		21	14½	1·49	39·1	61·5	81·2	88·8	93·4
29M	70% Parkgate and Silkstone 30% Anthracite duff	21	24¼	0·86	20·2	46·2	79·5	91·0	95·6
29N		21	20	1·05	22·7	43·8	73·6	86·8	94·8
29O		14	9½	1·47	1·0	15·6	49·9	72·5	91·0
18E	60% Thorncliffe 40% Flockton (S. Yorks.)	20	32½	0·63	43·8	75·2	92·9	96·0	98·1
18D		20	24	0·84	38·0	66·8	91·9	97·0	98·6
18F		18	19¼	0·94	3·1	23·4	63·8	83·4	94·4
18A		14	12	1·17	31·6	56·5	82·1	91·3	96·3
18L	As 18A, with 20% Barnsley	14	13	1·08	0·6	13·5	74·0	90·0	96·4
46C	Blend of coals from eight Yorkshire collieries	18	21½	0·84	20·7	54·3	90·5	95·7	97·8
46A		14	14	1·00	9·3	54·2	91·4	95·1	97·3
46B		16	—	—	17·5	54·5	83·2	93·5	97·3
22I	Mixture of four seams (Derby.)	18	21½	0·84	3·0	26·6	79·5	94·1	97·9
22J		18	18	1·00	4·0	19·5	64·9	83·5	92·4
22K		14	13	1·08	6·8	33·1	81·0	91·2	95·8

From the other results recorded in Table LXXXVIII, which, as already stated, cannot be directly compared with the same confidence as can those in the No. 29 series, the general inference can be drawn that increasing the rate of heating of an oven tends to reduce the size of the coke produced. This applies more particularly to the on 4-in. and on 3-in. sizes, the effect on the proportion of "useful coke" (whether that be regarded as of 1½-in. or 1-in. size) being usually small. For example, coke No. 18L, coked in a 14-in. oven, contained hardly any 4-in. and but little 3-in. sizes, yet the proportion of 1-in. size compares favourably with that of the cokes, in the same series of tests, made in the more slowly-heated ovens.

This coke, No. 18L, is of interest as a naturally-graded coke, 83 per cent. of it being of 1- to 3-in. size.

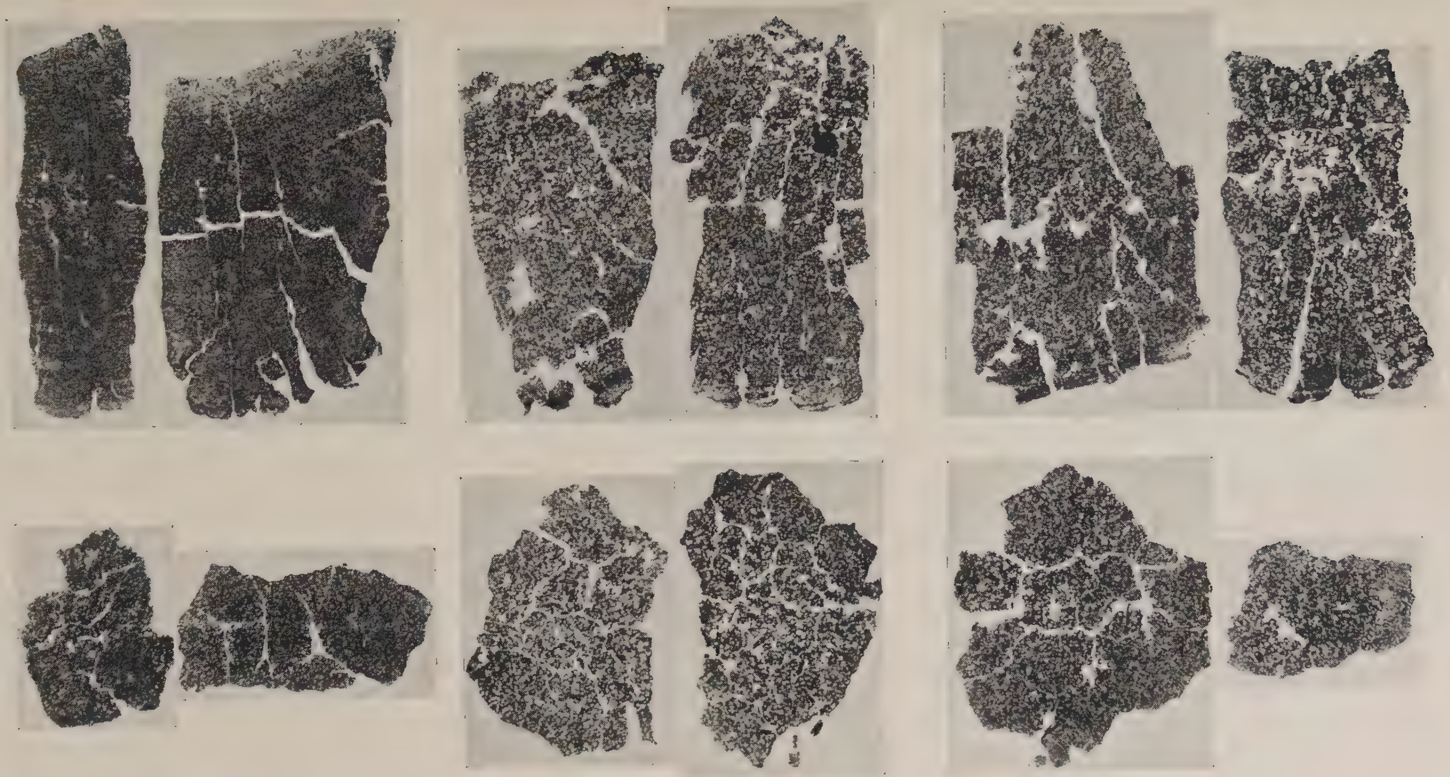
THE INFLUENCE ON THE HARDNESS OF THE COKE

The influence of the rate of heating of the oven on the hardness of the coke is illustrated in Table LXXXIX.

TABLE LXXXIX.—SHATTER INDICES OF COKES FROM THE SAME COALS COKED IN OVENS OF DIFFERENT WIDTHS.

Coke No.	Coal Used.	Width of Oven (inches).	Coking Time (hours).	Rate of Coking (in. per hour).	Shatter Indices.			
					2-in.	1½-in.	1-in.	½-in.
29B	Parkgate and Silkstone (S. Yorks.)	21	22½	0·95	74·1	86·7	94·1	97·4
29C		14	12	1·17	65·6	85·2	95·2	97·7
29D	Wath Wood and Swallow Wood (S. Yorks.)	21	22½	0·95	67·5	80·2	90·8	96·7
29E		14	13	1·08	65·0	80·9	91·1	96·9
29F	80% Parkgate and Silkstone 20% Wath Wood and Swallow Wood	21	24	0·87	72·9	85·9	94·8	97·7
29G		14	12¼	1·12	62·5	82·8	94·3	97·6
29K	80% Parkgate and Silkstone 20% low-temp. coke breeze	14	10	1·40	79·4	88·1	93·5	96·4
29J		21	14½	1·49	80·2	89·0	95·2	97·3
29M	70% Parkgate and Silkstone 30% Anthracite duff	21	24¼	0·86	72·3	90·1	96·4	98·1
29N		21	20	1·05	66·9	84·5	94·7	97·3
29O		14	9½	1·47	52·6	73·9	91·1	97·4
18E	60% Thorncliffe 40% Flockton (S. Yorks.)	20	32½	0·63	75·2	83·9	92·3	97·7
18D		20	24	0·84	68·1	83·0	91·8	97·7
18F		18	19¼	0·94	78·5	88·6	94·7	98·2
18A		14	12	1·17	70·8	80·2	91·3	96·5
18L	As 18A, with 20% Barnsley	14	13	1·08	68·9	86·6	94·8	98·1
46C	Blend of coals from eight Yorkshire collieries	18	21½	0·84	81·5	89·8	96·4	98·2
46A		14	14	1·00	76·5	87·4	94·0	97·3
46B		16	—	—	74·2	84·7	93·1	97·0
22I	Mixture of four seams (Derby.)	18	21½	0·84	67·8	84·4	93·6	97·8
22J		18	18	1·00	56·8	74·9	86·3	96·8
22K		14	13	1·08	58·0	74·1	86·8	96·1

The 2-in. shatter index is usually abnormally low for cokes made in 14-in. ovens or, generally, with very fast rates of heating. The hardness of the different cokes in Table LXXXIX is therefore better compared from their 1½-in. indices. Considering first the No. 29 series of cokes, with the high-volatile good caking coal (Parkgate and Silkstone mixture), and its blends, a harder coke is made in the wider oven; whilst with the high-volatile poor caking coal (Wath Wood and Swallow Wood), the narrower oven gives



No. 11. 24. 19B. 18A. 29E. 18L.

Plate XLIII.—Comparison of Structure of Cokes made from Different Types of Coal in 14-in. Ovens.

[To face p. 216.

rather the harder coke. It should be pointed out that in this series of tests the rate of heating in the wider oven (21-in.) was comparatively high, being on the average 0·9 inches (width) per hour. In older practice, with semi-silica ovens, a top-charged 21-in. oven would coke in about 28–32 hours, the average rate of heating being about 0·7 inches per hour. A coke made in a 20-in. oven with this slower rate of heating is included in the No. 18 series (No. 18E). Coke No. 18D was made in an oven of the same width but with silica walls, the rate of heating being thus increased to 0·84 inch per hour. This did not appreciably affect the hardness of the coke, but when the width of the oven was reduced to 18 inches (rate of heating 0·94 inch per hour) the hardness of the coke (No. 18F) was improved considerably. Further increase in the rate of heating (to 1·17 inches per hour), by using a 14-in. oven, caused a deterioration in the coke (No. 18A). These results suggest that there is an optimum rate of heating for a high-volatile good caking coal. If, however, a suitable quantity of a poor caking coal is blended with it, the "sponginess" of the coke can be modified and a rate of heating as high as about 1·1 inches per hour can successfully be used (cf. coke No. 18L).

The cokes of the No. 46 series were made from a complex blend of good and poor caking Yorkshire coals (high volatile). The hardest coke was made with the slowest rate of heating, as was the case also with the blend of Derbyshire coals (No. 22 series).

Whilst it would be unwise to generalise with regard to the influence of the rate of heating on the quality of the coke produced until a larger number of tests have been made, these results and others that we have obtained are suggestive. In Germany, satisfactory results have been obtained on coking low-volatile coals (20 to 25 per cent. volatile matter) in 14-in. ovens. Two examples of such cokes that we have tested (Nos. 10 and 11) have proved to be excellent in blast-furnace practice. Low-volatile caking coals yield cokes of good shape, but little fissured and with small and regular pores. Medium-volatile caking coals, such as those from Durham and Kent, have also been successfully coked in 14-in. ovens. High-volatile, good caking, Yorkshire coals have a tendency to yield cokes that are too spongy when they are coked in 14-in. ovens (in about 12 hours). This tendency can be counteracted by the admixture of a poor caking coal. These points are illustrated by the photographs of the various cokes reproduced on Plate XLIII, and by their characteristics recorded in Table XC.

The high-volatile, good caking coals yielded cokes (19B and 18A) of low apparent specific gravity and high percentage porosity. The values for these determinations do not, however, give an adequate idea of the coke structures, an expression for the size of the pores being necessary. The photographs on Plate XLIII give some indication of the enlarged pores of cokes Nos. 19B and 18A as compared with the structures of other cokes of the series. The effect of reducing the size of the pores by blending with a poor caking coal is illustrated by the shatter indices of cokes Nos. 18A and 18L.

TABLE XC.—CHARACTERISTICS OF COKES MADE IN 14-IN. OVENS (Cf. Plate XLII).

Coke No.	Coal Used.	Shatter Index (1½-in.).	Apparent Sp. G.	Open Pores (per cent.).	Total Pores (per cent.).
11	Low-volatile (Westphalia)	95·7	0·98	38·9	47·6
24	Medium-volatile (Kent)	87·9	0·95	42·8	50·8
19B	High-volatile, good caking (S. Yorks.)	82·0	0·82	44·9	54·0
18A		80·2	0·79	48·5	58·9
18L	Same as 18A, blended with 20% high-volatile, poor caking coal	86·6	0·90	41·6	52·3
29E	High-volatile, poor caking (S. Yorks.)	80·9	0·84	42·7	54·3

The results for the poor caking coals (No. 22 series in Table LXXXIX) and the blend of good and poor caking coals (No. 46 series in Table LXXXIX) are difficult to understand. Whereas an increase in the rate of heating (from 0·95 to 1·08 inch per hour) had but little, though slightly beneficial, result on the poor caking Wath Wood and Swallow Wood coals (see cokes Nos. 29D and E), a reduction in the rate of heating (from over 1·0 inch to 0·84 inch per hour) was apparently advantageous for the No. 22 and No. 46 series. Plates XLIV and XLV illustrate the structures of the "No. 46" and "No. 22" series of cokes in comparison with that of coke made from the same coal in slow-coking but cake-charged ovens. Further tests are necessary before the influence of the rate of heating on poor caking coals can be fully explained.

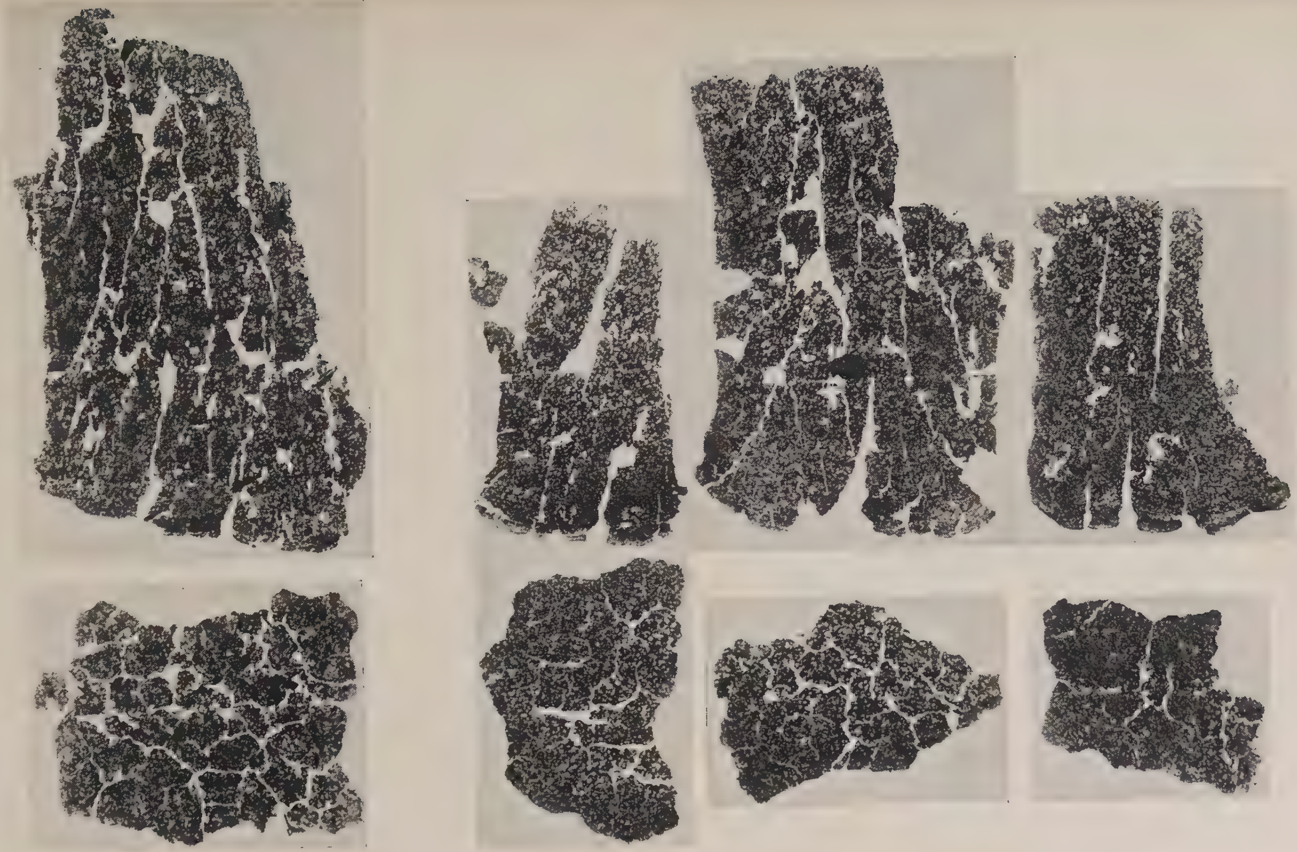
THE INFLUENCE ON THE DENSITY AND POROSITY OF THE COKE

The influence of the rate of heating on the density and porosity of the coke is illustrated in Table XCI.

Considering, as usual, the No. 29 series of cokes more particularly, it appears that with ordinary coking blends the faster rates of heating yield cokes of lower apparent density and higher total percentage porosity, the percentage of open pores, however, being reduced. The faster rates of heating also yield cokes of higher real specific gravity, no doubt because the temperature range over which the coal is plastic is wider.

THE INFLUENCE ON THE REACTIVITY AND COMBUSTION TEMPERATURE OF THE COKE

The results of tests of the specific "reactivity" of a number of cokes made with different rates of heating, carried out as described earlier in this Report (see p. 126), are recorded in Table XCII. These results should be considered in conjunction with those relating to the size and hardness of the cokes, for both these factors affect the reactivity of the coke in the blast-furnace.

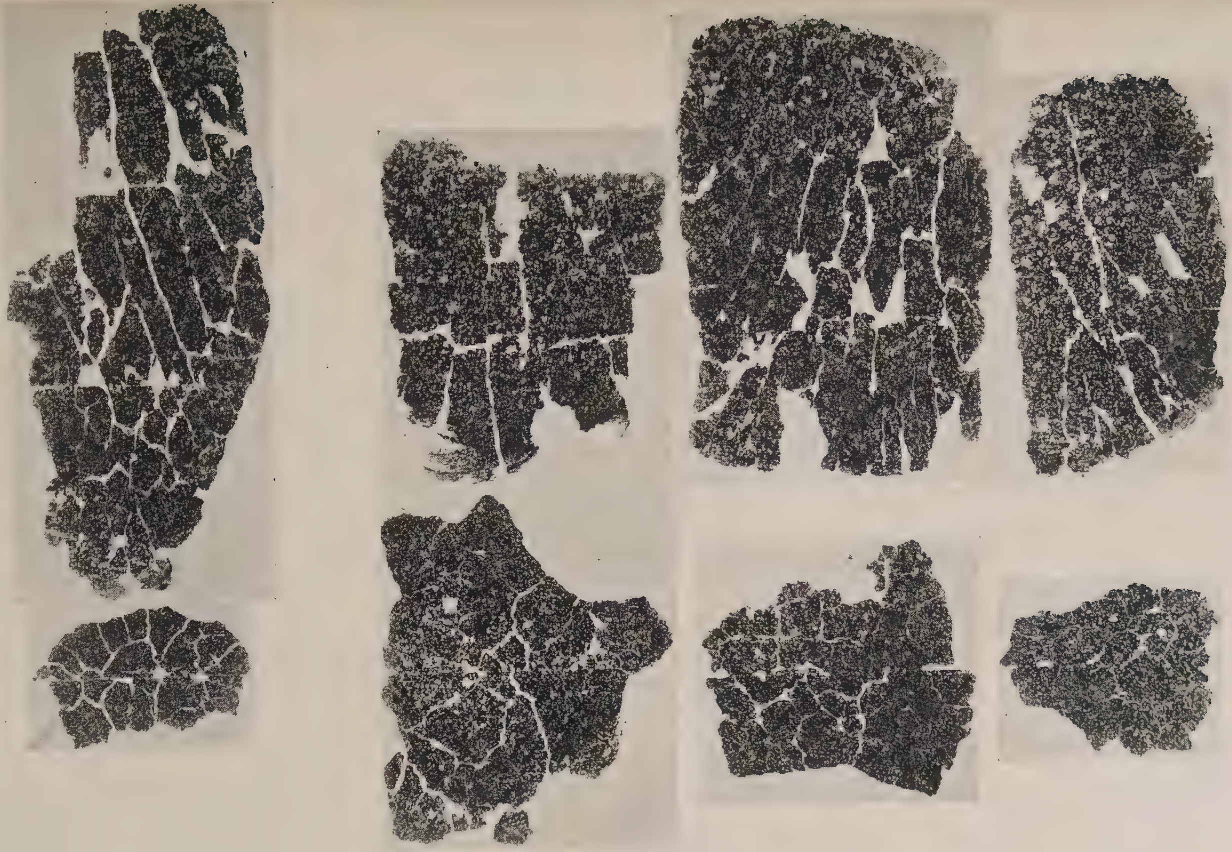


No.	46D (cake charge).	46A.	46B.	46C.
Coking time (hr.)	30	14	17(?)	21½

PLATE XLIV.—Structure of Coke made from Yorkshire Top-charged Coal at Different Rates of Heating. Compared with " Compressed " Coke from a Slow-coking Oven.

[*To face p.* 218.

X



No. 22H (cake charge).	22I.	22J.	22K.
Coking time (hr.) 26	21½	18	13

PLATE XLV.—Structure of Derbyshire Cokes made from Top-charged Coal at Different Rates of Heating. Compared with "Compressed" Coke from a Comparatively Slow-coking Oven.

[*To face p.* 218.

TABLE XCI.—THE DENSITY AND POROSITY OF COKES MADE FROM THE SAME COAL IN OVENS OF DIFFERENT WIDTHS.

Coke No.	Coal Used.	Width of Oven (inches).	Coking Time (hours).	Rate of Coking (inches per hour).	Apparent Sp. G.	Open Pores (per cent.)	Total Pores (per cent.).	Real Sp. G. (on ash-free basis).
29B	Parkgate and Silkstone (S. Yorks.)	21	22½	0·95	0·85	45·3	54·2	1·80
29C		14	12	1·17	0·85	37·5	55·0	1·83
29D	Wath Wood and Swallow Wood (S. Yorks.)	21	22½	0·95	0·86	44·1	52·7	1·74
29E		14	13	1·08	0·84	42·7	54·3	1·76
29F	80% Parkgate and Silkstone 20% Wath Wood and Swallow Wood	21	24	0·87	0·89	41·6	54·2	1·88
29G		14	12¼	1·12	0·88	36·8	54·6	1·85
29J	80% Parkgate and Silkstone 20% low-temp. coke breeze	21	14½	1·49	0·81	49·7	56·9	1·83
29K		14	10	1·40	1·00	32·3	46·2	1·81
29M	70% Parkgate and Silkstone 30% Anthracite duff	21	24½	0·86	1·03	36·0	43·7	1·78
29O		14	9½	1·47	1·11	31·2	39·0	1·76
18E	60% Thorncliffe 40% Flockton (S. Yorks.)	20	32½	0·63	0·84	45·8	54·4	1·76
18D		20	24	0·84	0·85	42·9	53·6	1·76
18F		18	19¼	0·94	0·83	46·3	55·6	1·80
18A		14	12	1·17	0·79	48·5	58·9	1·86
18L	As 18A, with 20% Barnsley	14	13	1·08	0·90	41·6	52·3	1·83

In general, it would appear that the faster rate of heating yields the more reactive coke, but no deduction can be drawn from these results with regard to the effect of the rate of heating the coal charge on that property of the resultant coke which determines its combustion temperature under standard conditions of burning. This is hardly surprising in view of the fact that some of the properties of coke upon which the attainment of a high combustion temperature appears to depend, namely, a high real specific gravity and a high percentage porosity, are improved by a rapid rate of heating the coal charge, whilst others, namely, a low "reactivity" and a high shatter index, are improved by a slow rate of heating.

The general conclusion to be drawn from the results, with respect to Yorkshire caking coals, is that the influence of the rate of heating the oven on the specific reactivity and temperature of combustion of the coke is small and unimportant in comparison with the influence on the size and hardness of the coke.

This conclusion is in accord with the results obtained by Haüsser and Bestehorn (*op. cit.*), whose combustibility tests on cokes made in ovens of different widths did not disclose any marked difference between cokes made in wide and narrow ovens, whereas differences in hardness were appreciable (Table XCIII).

TABLE XCII.—THE REACTIVITY AND TEMPERATURE OF COMBUSTION OF COKES MADE FROM THE SAME COAL IN OVENS OF DIFFERENT WIDTHS.

Coke No.	Coal Used.	Width of Oven (inches).	Coking Time (hours).	Rate of Coking (inches per hour).	Oxygen Disappears from Blast (inches).	Carbon Monoxide in Gas, 20 per cent. (inches).	Max. Temp. (°C.).	Average Temp. (°C.).
29B	Parkgate and Silkstone (S. Yorks.)	21	22½	0·95	5	11	1670	1540
29C		14	12	1·17	4½	11	1650	1510
29D	Wath Wood and Swallow Wood (S. Yorks.)	21	22½	0·95	4	9	1630	1520
29E		14	13	1·08	4	8	1670	1500
29F	80% Parkgate and Silkstone	21	24	0·87	6	9½	1665	1540
29G	20% Wath Wood and Swallow Wood	14	12¼	1·12	4½	9	1640	1555
29K	80% Parkgate and Silkstone	14	10	1·40	4½	9½	1670	1505
29J	20% low-temp. coke breeze	21	14½	1·49	5	10	1720	1580
29M	70% Parkgate and Silkstone	21	24½	0·86	4	10	1740	1600
29O	30% Anthracite duff	14	9½	1·47	3	10½	1660	1520
18E	60% Thorncliffe	20	32½	0·63	5	10½	1630	1485
18F	40% Flockton	18	19¼	0·94	4	9½	1700	1495
18A	(S. Yorks.)	14	12	1·17	5	10	1700	1590

GENERAL CONSIDERATIONS

In addition to the tests here recorded, which were carried out purposely to investigate the influence of the rate of heating the oven on the quality of the coke produced, the same quality of coal being top-charged to ovens of different widths, we have accumulated information regarding the general effect of the rate of heating during the course of other tests, made for different purposes. This information supplements our records, which are incomplete with respect to the effect of using slow-coking wide ovens. The difficulty in obtaining a sufficient number of results for slowly-heated ovens has lain in the fact that at most of the plants where tests have been made the wide ovens have been cake-charged and it has not always been practicable to top-charge them. The coke made in a top-charged narrow oven has always been superior to that made, from the same coal, in a cake-charged wide oven. This superiority has been due, however, mainly to the effect of top-charging.

TABLE XCIII.—COMBUSTIBILITY AND HARDNESS OF COKES MADE IN OVENS OF DIFFERENT WIDTHS (Haüsser and Bestehorn).

Coke No.	Width of Oven (inches).	Coking Time (hours).	Combustibility Index.	Abrasion Index.	Shatter Index (2-inch).
D1	21½	36	68·7	79·0	60·9
D2	18	22	68·1	80·3	61·0
D3	18	22	68·8	79·4	54·5
D4	16	18	68·1	82·3	54·1
D5	14	14	67·6	80·3	40·9
N1	18	22	—	75·1	54·0
N2	16	18	—	75·6	52·0
N3	14	14	—	75·6	46·3

In general we can say that an improvement in the quality of the coke, from Yorkshire and Derbyshire coals, is obtained by increasing the rate of heating from 0·6 or 0·7 inch per hour to between 0·85 and 0·95 inch per hour or, with suitable blending of the charge, even further. It is clear also that, unless the charge is carefully blended, the rate of heating in a 14-in. oven with a coking time of 12 hours or less is too rapid for high-volatile good caking coals. In a 14-in. oven, a difference of one hour in the coking time is equivalent to a difference in the rate of heating 0·1 inch per hour, which has a marked effect. It follows that the use of dry instead of wet coal in a 14-in. oven may be undesirable. If the coke produced from such an oven is spongy when the coking time is, say, 12 hours, it will prove advantageous to increase the coking time to about 15 hours, for example, by using wet coal. The same principle applies, though to a less degree, to 16-in. and even to 18-in. ovens.

Coke from modern narrow ovens has generally been found to be superior for blast-furnace use to that from the older ovens. Both in Germany and America most of the modern ovens are of 14-in. width, and the superiority of the coke made in them has usually been attributed to its greater "combustibility." We have shown that this general statement has no foundation in fact when the specific reactivity of the coke and its rate of combustion at the tuyeres of the blast furnace are considered. No advantage can be attributed to the coke from modern narrow-oven coking plants on the score of its "combustibility." Its undoubted advantage is due to: (1) its superior hardness, caused by (*a*) the substitution of top-charging for cake-charging, (*b*) suitable blending of the coal charge and (*c*) when the blend is suitable, the use of a rapid rate of heating; and (2) improvement in (closer grading of) the size of the coke, caused by (*a*) its greater hardness, (*b*) mechanical screening before loading and (*c*) greater uniformity of quality arising from more even heating of the ovens.

CHAPTER VII

QUENCHING, SCREENING AND HANDLING COKE

No attempt is here made to describe fully methods of quenching, screening and handling coke. Brief reference is made to various methods available, primarily with respect to their ease of control, to ensure that uniformly small amounts of water are left in the coke, to avoid the production of breeze at the ovens and to minimise the amount of breeze delivered at the blast furnace.

Quenching

The methods in principal use at present for quenching coke are : (1) to push it through a quenching hood (*a*) on to an inclined bench or (*b*) on to a coke car where the final quenching is given; (2) to push it through a coke guide on to a coke car, on which the coke is quenched at a central station.

The Inclined Bench.—It is desirable that the coke should be spread in a thin layer during quenching, so that excessive quantities of water need not be used and so that evaporation is rapid. An inclined bench on which the coke spreads out in a fan, with a layer maybe two or three feet thick near the oven, demands excessive quantities of water, and subsequent evaporation and drainage of excess water is slow; the more so if the coke from one oven has not been picked up before that from a nearby oven is discharged, so that the two " fans " overlap. " Spot " quenching, of hot spots that develop whilst the coke is standing, is often necessary and is responsible for variable and excessive amounts of moisture in the coke. This method of quenching cannot readily be standardised and variations in the water-content of the coke are to be expected when it is used.

The Coke Car.—As the coke is pushed through a quenching hood or coke guide on to a coke car, 40 or 50 ft. long, the car is moved at the same rate as the beam of the ram. In this way the coke is spread evenly in a thin layer over the length of the car.

The method originally used by Mr. G. T. Purves at Orgreave coke ovens, Sheffield, was to push the coke through a quenching hood to which sufficient water was supplied to cool the coke to about 500–600° C. The even layer of coke on the car was then passed at a uniform speed under a horizontal water spray pipe to which a definite quantity of water was supplied, through $\frac{1}{4}$-in. holes, under a head of 125 ft. In present practice, the coke is pushed on a fast gear and the quenching hose is not coupled to the hood, but the stream of water is directed on to the coke as it emerges from the hood, which is thus used as a guide. The use of the hose in this manner is mainly to break up the cake and allow the coke, which is red-hot as it passes for final spraying, to spread evenly on the car. After spraying, the car is allowed to stand during five minutes to allow of evaporation of water from the coke, which is then passed over a bar screen into wagons. The coke when loaded into wagons is still almost too hot to hold in the hand, but the quenching is so regular that but little trouble and expense are experienced through burnt wagons. The records of moisture-contents of the coke as loaded at the ovens (Orgreave) and as received at the blast-furnaces (Frodingham) over a period of six months, given in Table XCIV, bear witness to the success of this method of quenching. The figures relate to 85,410 tons of coke delivered during the six months.

TABLE XCIV.—THE MOISTURE-CONTENTS OF COKE AT THE OVENS AND AT THE BLAST FURNACES.

1929. Week Ending.	Moisture (per cent.).	
	At Ovens (Orgreave).	At Blast Furnaces (Frodingham).
May 4th . . .	0·3	0·9
May 11th . . .	0·3	1·1
May 18th . . .	0·3	1·4
May 25th . . .	0·2	1·5
June 1st . . .	0·2	1·7
June 8th . . .	0·3	1·7
June 15th . . .	0·2	1·2
June 22nd . . .	0·2	1·6
June 29th . . .	0·2	1·5
July 6th . . .	0·3	0·8
July 13th . . .	0·3	0·7
July 20th . . .	0·2	0·7
July 27th . . .	0·2	1·5
Aug. 3rd . . .	0·3	1·4
Aug. 10th . . .	0·6	1·6
Aug. 17th . . .	0·4	0·9
Aug. 24th . . .	0·3	1·3
Aug. 31st . . .	0·2	1·1
Sept. 7th . . .	0·3	0·6
Sept. 14th . . .	0·5	1·4
Sept. 21st . . .	0·2	0·8
Sept. 28th . . .	0·2	0·8
Oct. 5th . . .	0·3	1·1
Oct. 12th . . .	0·3	0·9
Average . . .	0·3	1·2

The coke sent from the ovens thus consistently contained well under 1 per cent. of moisture and it is doubtful whether even " dry quenching " could give a better result.

Central Quenching.—When central quenching is practised, the coke is rapidly pushed through a guide on to the car and there subjected to a sudden quenching by the delivery of a predetermined quantity of water through spray pipes. The steam produced is carried away through a shaft to the upper air.

TABLE XCV.—THE MOISTURE-CONTENTS OF COKE AT THE OVENS, CENTRAL QUENCHING.

(A) *Average weekly records.*

Week Ending	Moisture Content (per cent.).	Week Ending	Moisture Content (per cent.).
Sept. 7th, 1929	2·0	Dec. 7th, 1929	1·8
Sept. 14th	1·9	Dec. 14th	2·1
Sept. 21st	1·7	Dec. 21st	1·9
Sept. 28th	1·9	Dec. 28th	2·6
Oct. 5th	2·8	Jan. 4th, 1930	2·4
Oct. 12th	2·1	Jan. 11th	1·9
Oct. 19th	1·9	Jan. 18th	1·5
Oct. 26th	1·7	Jan. 25th	2·0
Nov. 2nd	2·5	Feb. 1st	1·7
Nov. 9th	2·3	Feb. 8th	1·4
Nov. 16th	2·6	Feb. 15th	1·5
Nov. 23rd	2·1	Feb. 22nd	1·9
Nov. 30th	2·3	Mar. 1st	1·7

Average for six months, 1·97 per cent.

(B) *Daily records, February,* 1930.

Date.	Moisture Content (per cent.).	Date.	Moisture Content (per cent.).
Feb. 1st	2·1	Feb. 15th	1·9
2nd	1·7	16th	2·7
3rd	1·3	17th	1·7
4th	1·2	18th	2·5
5th	1·1	19th	1·0
6th	1·3	20th	2·0
7th	1·8	21st	2·2
8th	0·9	22nd	1·1
9th	1·5	23rd	1·2
10th	1·5	24th	1·6
11th	1·2	25th	2·8
12th	1·3	26th	1·3
13th	1·9	27th	1·4
14th	1·3	28th	1·8

Average for month, 1·61 per cent.

The essential difference between the method previously described and central quenching is that in the former the layer of coke in the car, which is more even, is moved under a single water spray, whereas in central quenching the coke car is stationary and a number of water sprays are used, the local concentration of water being greater. Central quenching has the advantage of being able to deal effectively with the steam produced. Quenching occupies about one minute and is followed by a period of two or three minutes during which water drains from the coke which is then discharged on to a cooling wharf. "Spot" quenching with a hand hose may be necessary at this stage.

We are indebted to Mr. G. A. Hebden for the records in Table XCV of moisture-contents of coke produced at Parkgate, Yorkshire, where the central system of quenching is practiced.

The Greensmith Quencher.—The Greensmith quencher installed at Wharncliffe Silkstone colliery consists of a water tank to which the coke is fed from a 6-ft. hearth placed in front of the oven. The coke is carried through the tank by a conveyer, each piece being immersed in the water during about one minute. The whole of the operations of discharging and quenching occupies but 2 minutes, but a cooling period of about 30 minutes is desirable if the moisture-content of the coke is to be reduced to 1 per cent. This long cooling period seems to be the only disadvantage of the method, for the consumption of water is low and the amount of breeze formed is small. During one year's working, the average moisture-content of the coke was 1·2 per cent. at the ovens and 3·0 per cent. at the blast furnaces.

Dry Quenching.—Methods of dry quenching coke have been applied on the Continent and in America, as well as at gas-works in this country. By dropping the hot coke into a chamber that can be sealed and circulating an inert gas through it, with a waste-heat boiler in series, the sensible heat of the coke can be recovered.

It has been claimed that the absence of sudden cooling, such as is given by the application of water under high pressure, causes the coke to be stronger. The forces of contraction during the cooling of coke, however, are small compared with those operating within the oven when shrinkage fissures are formed, whilst the additional "handling" to which the coke is subjected when it falls into the cooling chamber is productive of much breeze (see Beebee, *The Gas Journal*, 1927, 179, 284).

Dry-quenched coke, containing no moisture at the ovens, would absorb between 1 and 2 per cent. during its transport to the blast furnaces.

Summary.—For the modern high-speed operation of coke-oven plants with large ovens, central quenching is probably the most satisfactory method and it allows of fair control over the moisture-content of the coke. Alternatively, the use of a coke-car to provide an even layer of coke which can be subjected to a final, standardised, spraying is to be recommended. The Greensmith quencher also enables standard treatment to be accorded to the coke. If the coke is quenched on an inclined bench its moisture-content is usually variable.

SCREENING AND HANDLING

When coke is loaded from an inclined bench, hand loading into wagons with forks is the method usually employed, the pieces of coke that pass through the forks being collected separately. This method is fairly satisfactory as regards the removal of the breeze formed in the oven and during the discharge of the coke, but as much breeze again is formed on dropping the coke into the wagons (see p. 27). This disadvantage applies to all methods of loading coke that involve the dropping of it from a height, and the only way of countering it is to arrange that the height through which the coke is dropped shall be small, *e.g.*, by the employment of adjustable loading booms (as in Fig. 49).

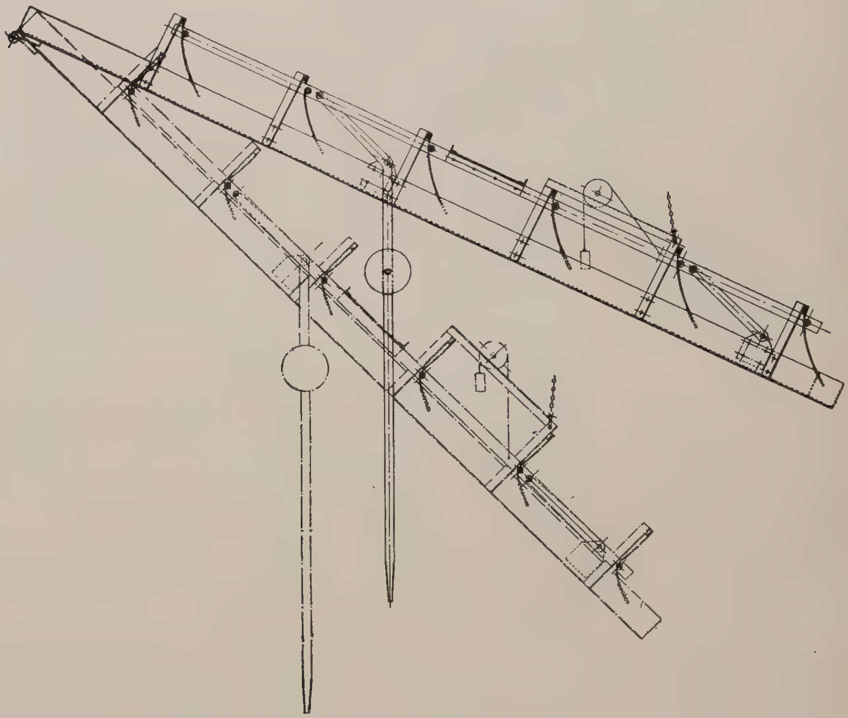


FIG. 49.—Adjustable Loading Boom to reduce Drop Experienced by Coke on Loading into Wagons.

Other methods of handling coke employ a steeply-inclined bench, or cooling wharf, whence the coke passes through finger gates on to a rubber band conveyer; or a coke car, drawn up an incline or raised to the necessary height by a vertical hoist, which delivers the coke over a fixed bar screen.

When conveyers are used, screening may be effected by jigging screens, rotating cylindrical screens or grizzlies. Without discussing the merits of the various methods, it must be pointed out that each drop from a height that the coke receives during screening and handling causes breakage, so that the design of screening plant should aim to reduce the amount of dropping to a minimum. Fixed bar screens are not as efficient as moving screens but are cheap to maintain. Grizzlies appear to be becoming increasingly popular and are generally satisfactory. The screening out at the ovens of all coke pieces less than 1–1½ inches is to be recommended.

Reference has been made earlier (p. 30) to the suggestion that coke should be deliberately handled roughly at the ovens, in an attempt to reduce its liability to fracture further during subsequent handling, and it has been shown that the idea is unsound (see Table XII, p. 30). It is preferable to make every effort to increase the hardness of the coke, so that its inherent liability to form breeze is reduced.

If the breeze formed in the oven and during the discharge of the coke has been effectively removed, and if the coke is loaded into wagons by means of an adjustable boom, there will be but little breeze in the coke when it leaves the plant. Some breeze is unavoidably formed during transport. At the blast furnaces, as at the ovens, care should be taken to avoid dropping the coke through an unnecessary height; for example, into empty storage hoppers. Arrangements should be made to maintain a level of coke in the hoppers. To remove any breeze formed up to the stage when the coke is run into skips, a fixed bar screen at the bottom of the hopper, with 1–1½-in. spaces between the bars, is recommended. Such breeze is of little or no value in the blast furnace but can be made use of elsewhere. With every endeavour thus made to maintain a high proportion of "useful coke" (greater than about 1½-in. size) delivered to the blast furnace, economical and smooth working of the furnace will be promoted.

CHAPTER VIII

METHODS OF RESEARCH ON BLAST-FURNACE COKES

The usual method of testing coals, or mixtures of coals, as regards their value for coke manufacture is to carry out large-scale oven trials, the appearance of the coke being often a good guide as to its quality. Such a method has obvious advantages and, at first sight, seems eminently practical. Nevertheless it has several defects.

For example, a test of this description must not interfere with the usual routine of the plant, but must await a convenient time. If, as sometimes happens, there is a considerable interval between the arrival of the coal at the plant and its use at the ovens, deterioration, sometimes serious, in the caking properties of the coal occurs through " weathering." One instance of the effect of oxidation of coal during storage has been cited (p. 211). Another relates to a mixture of poor caking Derbyshire and Yorkshire coals which was sent to Cumberland for test in comparison with a similar test at a Derbyshire plant :

Coke No.	Where Coked.	Oven Width (in.).	Coking Time (hr.).	Rate of Coking (in. per hr.).	Shatter Index.	
					2-in.	1½-in.
22B	Derbyshire	21	28¾	0·73	48	66
22C	Cumberland	21	24	0·87	34	59

Both cokes were made from compressed charges. According to the information obtained on coking similar coals, the faster rate of heating for coke No. 22C should have tended to produce a better coke. Actually, it was the worst coke we have tested.

If, as is usual, the effects of a number of variables must be studied, full oven tests of a coal become expensive. We have found that it is by no means essential to have recourse to large-scale tests, but that the information desired can be obtained by simpler means. A large-scale test need only be carried out to confirm an optimum result obtained as the result of a series of simpler tests, such as " box " tests.

Box Tests

A number of variants of what may be termed " box tests," in which a comparatively small quantity of coal enclosed in a box is introduced with the charge into the oven, have been tried. The most satisfactory method of test has made use of old washery plates for the construction of the box. The mode of procedure has been as follows.

The box, of washery plates having $\frac{3}{8}$-in. perforations, is 4 ft. long, 14 or 16 in. wide and $1\frac{1}{2}$ ft. deep and holds about 300 lb. of coal (see Fig. 50). Such boxes, containing the coal or mixture of coals to be tested, are preferably arranged within the oven charge midway from top to bottom, in order that the resultant coke may be more fairly representative of the average contents of an oven (see p. 108). Such an arrangement is only possible when the oven is cake-charged, the boxes being then placed in the cake-box after a portion of the cake has been prepared. When the oven is top-charged, the boxes must be placed on the oven sole at the narrow end of an empty oven, the ordinary charge being then admitted.

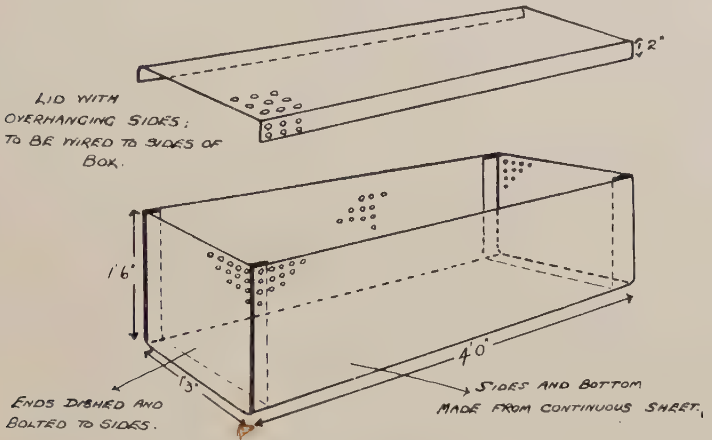


FIG. 50.—Diagram of Box for Box Test.

It is then preferable that the boxes should be shorter, say 3 ft. long, and deeper, say $2\frac{1}{2}$ ft. deep, so that less of the resultant coke is the abnormally fissured coke of the oven sole. Alternatively, if a coke car is used, the box can be pushed by the ram to near the discharge end of the oven and, when the oven is coked, pulled out by hooks after the front of the charge has been pushed out.

The coke contents of such boxes are usually sufficient to provide three shatter tests. Although the test cokes are sufficiently isolated from the oven charge to permit of their ready recovery, they have been surrounded by coal in the oven and the perforations in the plates have allowed access of tarry vapours and gases during the coking process, as in an ordinary charge.

It is possible with such boxes to simulate the conditions of either cake-charging or top-charging, the former by providing a loosely-fitting false lid within the box so that the coal can be subjected to the compression of the stamper legs, and the latter by the use of an overhanging lid so that the contents of the box are unaffected by the compression in the cake-box. Since our large-scale tests have shown that cake-charging yields an inferior coke to that produced when top-charging is adopted, we have confined our box tests to the latter condition.

A comparison of the shatter test results for cokes made from the same coal in full oven charges and in box tests is given in Table XCVI.

TABLE XCVI.—A COMPARISON OF COKES MADE IN BOX TESTS AND IN LARGE-SCALE OVEN TESTS.

Coke No.	Coal Used.	Condition of Test.	Shatter Indices.	
			2-in.	1½-in.
29B	Parkgate and Silkstone	Full-scale oven	74	87
29B (*b*)		Box, 2 ft. from oven sole	70	87
29J	Parkgate and Silkstone 80% Low-temp. coke breeze 20%	Full-scale oven	80	89
29I (*b*) iv		Box, 2 ft. from oven sole	85	89
29M	Parkgate and Silkstone 70% Anthracite duff 30%	Full-scale oven	72	90
29L (*b*) iii		Box, 2 ft. from oven sole	85	90
3F (III)	Parkgate and Silkstone	Full-scale oven	74	85
3F (III) (*b*)		Box, on oven sole	75	86
13E (I)	Parkgate 90% Barnsley 10%	Full-scale oven	74	88
13E (*b*)		Box, on oven sole	75	87
22Lm	Derbyshire	Full-scale oven	70	85
22O (*b*)		Box, on end on oven sole	72	85

Most of these results are the averages of three or more shatter tests, though for the "box" cokes 25 lb. were sometimes used for the test instead of the usual 50 lb. There is close agreement as regards the 1½-in. shatter indices between the results of the "box" coke and the full oven coke from the same coal. For the 2-in. index the agreement is not so good. This is hardly surprising, for the boxes were sometimes only 14 in. wide. The conditions of coking were thus similar to those of a 14-in. oven which we have shown (p. 104) to yield cokes for which the 2-in. shatter indices are abnormal. The 2-in. shatter indices of blend cokes, such as 29J and 29M, are also abnormal.

The size of the coke made in a box test does not usually compare satisfactorily with that of coke made in a large-scale oven, being usually larger. The effects of different variables on the size of the coke can, however, be gauged by a series of box tests.

The Northern Coke Research Committee have experimented in a similar manner with rectangular and cylindrical tins and have found good agreement between the results of shatter tests of cokes made from the same coals in large-scale ovens and in such tins, the rectangular tins being preferable (*Fuel*, 1929, **8**, 429).

A disadvantage of tests made in iron or steel boxes is that the box does not last for more than three or four tests, the metal becoming brittle through absorption of carbon. During the course of our work we have made over 100 box tests, but in doing so have exhausted the supply of discarded washery plates from five plants.

BAG TESTS

A number of " bag tests " have been made, in which the samples of coal were contained in jute sacks surrounded by wire netting. These sacks were disposed midway from top to bottom of the cake-box and covered with slack. The half cake was then charged and the remainder of the oven filled from tubs. Results of shatter tests of cokes made in this way are recorded in Table XCVII.

TABLE XCVII.—A COMPARISON OF COKES MADE IN BAG TESTS AND IN LARGE-SCALE OVEN TESTS.

Coke No.	Coal Used.	Condition of Test.	Shatter Indices.	
			2-in.	1½-in.
17H	Barnsley	Full-scale oven	69	79
17H (*b*)		Bag	81	84
17I	Silkstone	Full-scale oven	62	73
17I (*b*)		Bag	66	75
17K	Parkgate	Full-scale oven	79	89
17K (*b*)		Bag	81	89

The agreement between the results for the full-scale oven cokes and the bag cokes is only good with cokes Nos. 17K and 17K (*b*). The coke from a bag retained the shape of the bag, having rounded ends, and the longitudinal fractures start from the centre of the bag and run to the circumference, as in a horizontal gas-retort, an effect avoided when a rectangular box is used.

EXPERIMENTAL OVENS

The exhaustion of the supply of washery plates for the construction of boxes, to which we have referred previously, led us to consider the use of an experimental oven for similar small-scale tests.

Experimental ovens have been built at a number of coke-oven plants for test purposes. We are indebted to Mr. H. Morfey of the Shelton Iron, Steel and Coal Co., Ltd., Stoke-on-Trent, for carrying out special tests in his experimental oven for comparison with the results of full-scale oven tests on the same coal. The experimental oven was 4 ft. long, 3 ft. high and 15 in. wide and coked a wet charge of coal in from 12 to 15 hrs. The full-scale oven tests were made in an 18-in. oven with a coking time of about 22 hrs. Three shatter tests were made on each of the cokes from the large-scale oven but only one on those from the experimental oven. The results are recorded in Table XCVIII.

TABLE XCVIII.—A COMPARISON OF COKES MADE IN AN EXPERIMENTAL OVEN AND IN A FULL-SCALE OVEN.

Oven No.	Shatter Indices.				Trommel Index (40 mm.).	
	Large-scale Oven.		Experimental Oven.		Large-scale Oven.	Experimental Oven.
	2-in.	1½-in.	2-in.	1½-in.		
8	59	68	43	79	42	53
18	52	78	48	76	41	49
35	63	73	55	73	43	37
37	62	78	52	78	44	51
19	65	77	69	80	49	61
22	62	77	68	80	48	59
Average	61	75	56	77	44	52
Average excluding No. 8	61	77	59	77	44	52

The 2-in. shatter indices do not agree well, owing no doubt to the experimental oven having been so rapidly heated, cokes that have been made in rapidly-heated ovens having, as we have seen (p. 104), abnormal 2-in. shatter indices. The 1½-in. indices, particularly if the anomalous result for No. 8 oven is excluded, agree well. The trommel indices do not agree in actual values, but, in general, when the large-scale oven coke had a high trommel index the experimental oven coke had a high index also. It is possible that, in analogy with the shatter indices, if this index had been determined for a smaller screen than the 40 mm., agreement might have been shown.

An experimental oven similar in most respects to that at Stoke-on-Trent has been erected by the Midland Coke Research Committee at a coke-oven plant near Sheffield. Its design is illustrated in Fig. 51 and on Plate XLVI. The oven is heated by downward combustion of gas in a series of vertical flues. The waste gases are collected in a common flue below the vertical flues and pass thence to a chimney, there being no sole flues so that the bottom heat is restricted. The gas-supply for each flue can be controlled by a cock and the air-supply, drawn in from the side, by a slide. Provision is made for measuring the flue temperatures. The coal charge, about 5 cwt., is delivered from a hopper mounted on the top of the oven and levelled through an opening in the discharge door. This door is controlled by a pulley and balance weight and is fixed in position by a bar and wedge, the door-frame being luted. The gases and vapours evolved during the carbonisation escape through a vertical pipe into the air. The oven is discharged by dragging the coke from it at the front, where it is quenched.

An oven of this type can be recommended for the testing of

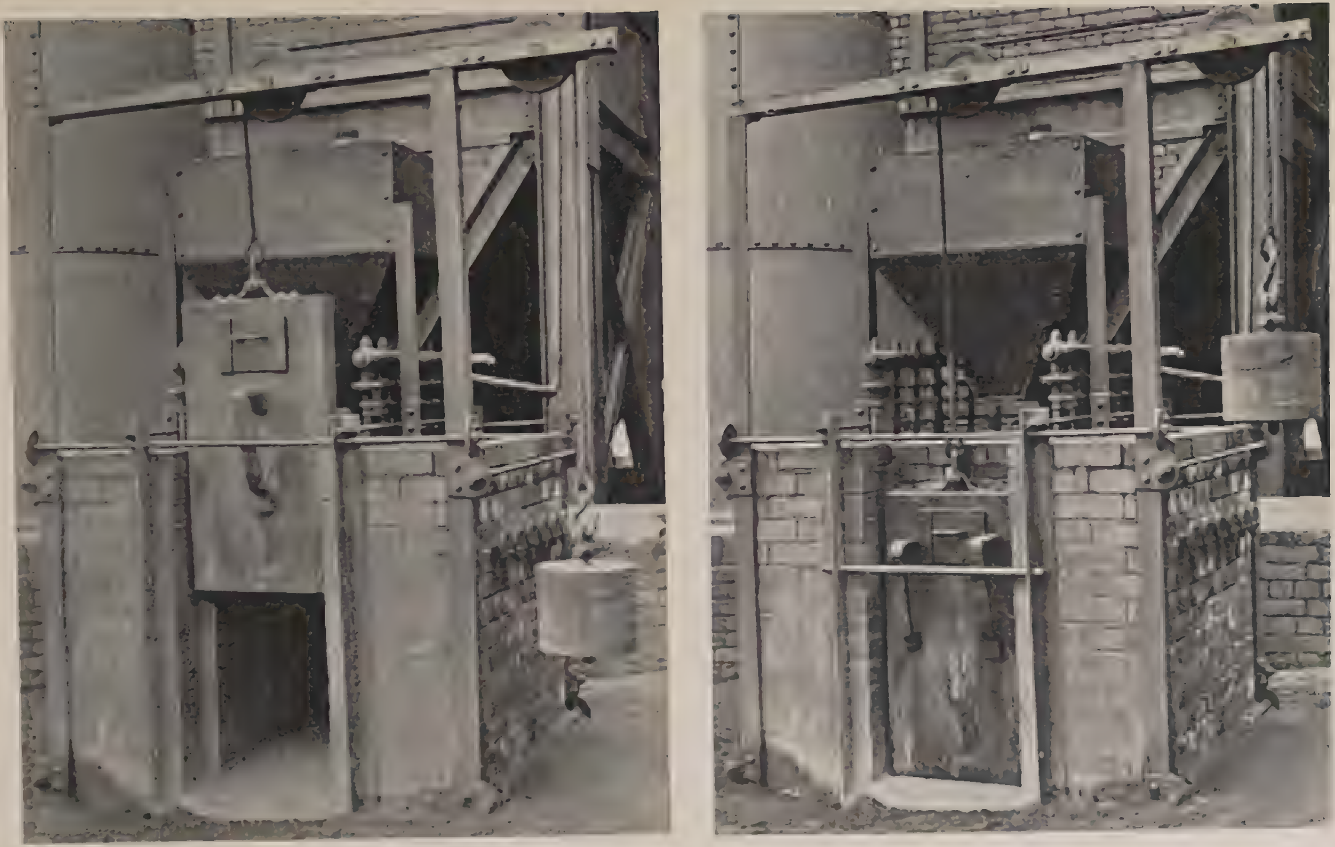


PLATE XLVI.—Views of Experimental Oven (Midland Coke Research Committee).

[*To face p* 232.

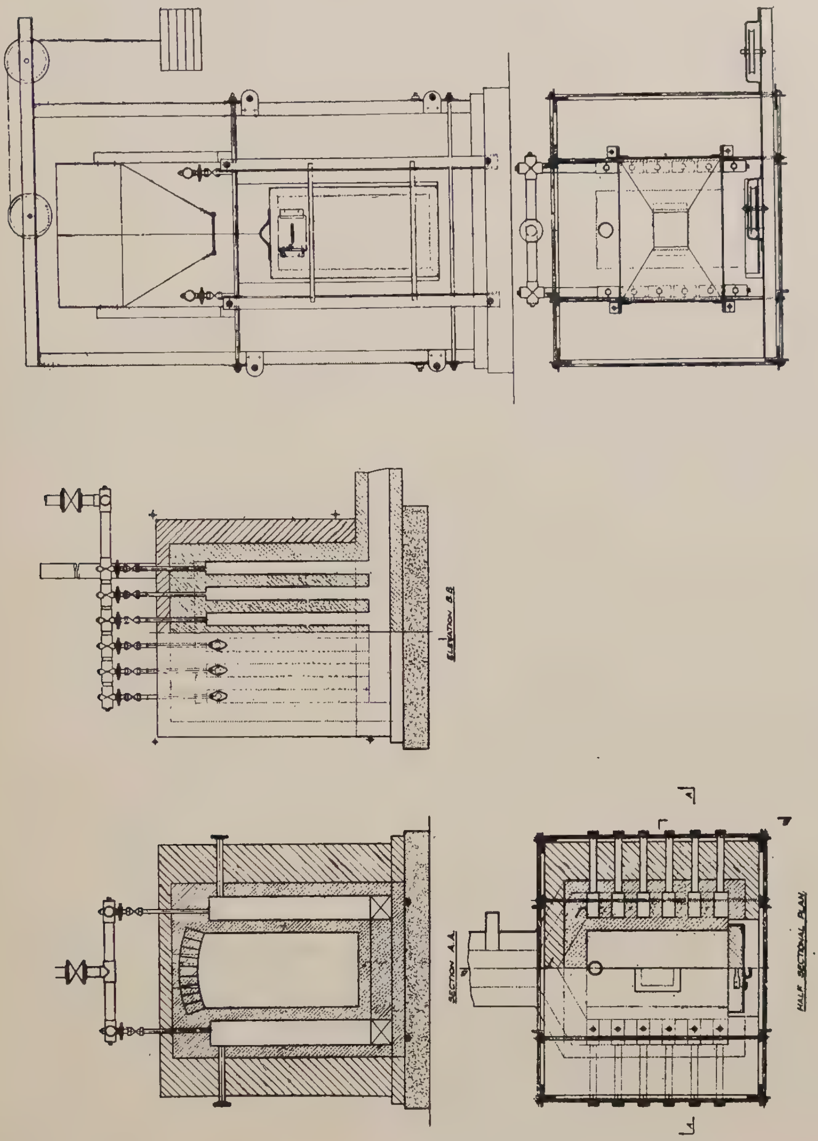

ELEVATION B.B
SECTION A.A
HALF SECTIONAL PLAN

FIG. 51.—Experimental Oven (Midland Coke Research Committee).

coals and for studying the effects on the quality of the coke of different factors, such as the size of the coal, blending and the rate of heating, the shatter test being used as the principal means of assessing the quality of the coke. A final confirmatory test with a large-scale oven can be made under the optimum conditions indicated by the experimental oven tests.

Blast-furnace Trials

Difficulties arise in the use of the blast furnace as "experimental" apparatus by reason of the large scale of the operations and the many factors that may be presumed to affect the working of the furnace. To reduce these difficulties, it is essential that when a change in the conditions of working is made, as when a new quality of coke is used, ample time should be given for changes in the burden to be adjusted and that the subsequent test under the newly-standardised conditions should not be of too short duration. A preliminary blast-furnace trial that we have carried out has afforded valuable information as to the more important observations to be made during such trials.

The matter of immediate moment to the blast-furnace operator when testing a particular coke is the consumption per ton of pig of a particular grade, given regular working of the furnace and a high output. It has usually been found that with any improvement in the quality of the coke the furnace drives more easily, the blast-furnace drops and the ratio CO_2/CO of the top gases increases. A trial involves observations of: (1) the quantity and quality of (*a*) the ore, (*b*) the coke and (*c*) the limestone; (2) the quantity, temperature, pressure and humidity of the blast; (3) the composition of the top gases; and (4) the quantity and quality of the pig iron produced.

It would be difficult to make absolute measurements of the quantity of blast entering the furnace during a prolonged trial, and it is not necessary to do so. All that is required is the variation in the quantity from hour to hour as a guide to the working in the hearth. This can be obtained by the use of a differential gauge measuring the drop in pressure across a standard restriction (at a partly-closed valve, for example) in the blast main. Rather than that periodical observations should be made of such differential pressure-gauge readings, it is desirable that they should be continuously recorded by automatic means. The same applies to the analyses, for carbon dioxide and carbon monoxide, of the top gases.

As regards measurement of the quality of the coke, difficulties in sampling may arise. The ideal size analysis would be that of the coke as dropped at the charge level, but this can rarely be obtained. The coke should be sampled (see Part I, Chapter VII) at the nearest point to the charge level, after it has been subjected to any dropping into hoppers or skips. If the coke is loaded directly from wagons into skips the process of sampling is simplified. Frequent samples should be taken. An occasional complete size analysis, with regular determinations of the amounts of through $1\frac{1}{2}$-in. and 1-in. sizes, should suffice. Fifty pounds of the coke over 2-in. size should be collected for shatter test, three such tests daily affording information as to the average hardness of the coke.

The information most urgently required from blast-furnace trials of this character is, perhaps, that relating to the effect of the size of the coke on the fuel consumption and the working of the furnace. It is hoped to arrange for such trials in the near future.

APPENDIX

APPENDIX

The principal results of tests on all the cokes examined by the Midland Coke Research Committee are recorded in this Appendix.

In the records of shatter indices, when an asterisk is placed against the values the average deviation is greater than 3·0 for the 2-in. and greater than 2·0 for the 1½-in. index, not more than three tests having been made (see p. 97).

Coke No. and District.	Coke Data.					Average Size Analysis (per cent.).					
	Details of Coals used.	Method of Charging.	Moisture in Coal (per cent.).	Coking Time (hr.).	Oven Width (in.).	On 4 in.	On 3 in.	On 2 in.	On 1½ in.	On 1 in.	On ½ in.
1 S. Wales	Two Foot Nine Upper 4 Ft.	Top charge	9·0	48	19	—	—	94·4	96·7	98·0	98·5
1A S. Wales	Upper 6 Ft. Upper 9 Ft.	Top charge	Ditto			70·1	87·1	95·8	98·4	98·8	99·1
2 Durham	Brockwell 53·3	Top charge	3·5	15½	17¾	—	—	87·1	94·2	97·2	98·2
2A Durham	Busty 47·7	Top charge	Ditto			8·0	40·3	76·1	89·2	95·3	97·2
3A S. Yorks.	Silkstone 39, Parkgate 33, Barnsley 15, Wath Wood and High Hazel 13	Top charge	11·0	30	20½	—	—	81·8	92·2	97·3	98·6
3B S. Yorks.	Silkstone 44·4 Parkgate 55·6	Top charge	10·0	30	20½	38·7	71·0	87·8	94·4	97·8	99·0
3C S. Yorks.	As for 3B	Top charge	10·0	48	Beehive	5·0	19·0	58·6	85·9	96·9	98·2
3D S. Yorks.	As for 3B	Top charge	10·0	72	Beehive	12·6	41·7	76·0	90·8	97·0	98·3
3E (I) S. Yorks.	Parkgate 66·7 Silkstone 33·3 } 1"–½"	Top charge	3·6	30	20½	—	12·9	40·0	63·5	84·1	94·3
3E (II) S. Yorks.	Ditto ½"–⅜"	Top charge	3·7	30	20½	—	26·4	51·2	68·9	85·9	93·9
3E (III) S. Yorks.	Ditto ⅜"–¼"	Top charge	2·7	30	20½	—	27·9	58·6	75·1	89·9	96·2
3E (IV) S. Yorks.	Ditto ¼"–⅛"	Top charge	2·6	30	20½	—	28·8	68·5	83·4	93·5	97·7
3E (V) S. Yorks.	Ditto ⅛"–1/16"	Top charge	2·8	30	20½	—	20·0	67·4	86·2	96·6	98·9
3E (VI) S. Yorks.	Ditto thro' 1/16"	Top charge	3·6	30	20½	—	17·8	69·7	89·9	97·0	98·7
3E (VII) S. Yorks.	Ditto thro' ¼"	Top charge	2·3	30	20½	7·8	32·9	76·2	89·3	96·1	98·4
3E (VIII) S. Yorks.	Ditto thro' ⅛"	Top charge	4·3	30	20½	13·5	39·9	77·9	88·5	95·4	97·6
3F (I) S. Yorks.	Ditto Slack thro' ¼"	Top charge	6·6	30	20½	3·1	28·6	76·5	91·0	97·1	98·4
3F (II) S. Yorks.	Ditto Slack thro' ⅛"	Top charge	5·9	30	20½	4·4	25·1	75·3	92·3	97·9	98·9
3F (III) S. Yorks.	Ditto Ordinary slack	Top charge	11·1	40	20½	52·7	80·4	92·7	96·4	98·1	99·0
3F (IV) S. Yorks.	Ditto Slack thro' ½"	Top charge	5·4	30	20½	7·1	27·1	72·1	85·9	95·1	98·0
3F (III) (*b*) S. Yorks.	As for 3F (III)	Box test	11·1	40	20½	68·0	78·3	87·3	91·1	94·7	97·5
3F (*b*) s. i. S. Yorks.	Ditto, Slurry	Box test	20·6	40	20½	68·5	86·9	97·2	98·6	99·3	99·6
3F (*b*) s. ii. S. Yorks.	Ditto, Slurry	Box test	19·0	40	20½	89·5	92·2	94·9	96·6	97·9	98·8
3G (I) S. Yorks.	Barnsley 54 Wath Wood and High Hazel 46 } Slack thro ¼"	Top charge	10·8	30	20½	14·3	39·8	76·8	88·0	94·5	96·9
3G (II) S. Yorks.	Slack thro' ⅛"	Top charge	9·8	30	20½	5·1	16·8	66·1	86·2	94·0	95·9
4 S. Yorks.	Haigh Moor Beamshaw Barnsley	Cake charge	12·0	33	21	—	—	39·0	53·2	74·4	85·3
5 Durham	Harvey 50·0 Busty 50·0	Cake charge	14·0	31	21	—	—	79·4	88·0	96·5	98·3
6 Durham	Five Quarter 37·0 Brockwell 34·0 Ballarat 29·0	Top charge	3·0	30	20½	—	—	90·3	95·0	97·7	98·5
7 S. Yorks.	Parkgate 100	Top charge	12·8	28	18	—	—	60·7	79·7	94·8	98·2
8A S. Wales	Coking coal 88·9 Anthracite duff 11·1	Top charge	11·0	28	17½	—	—	85·5	94·1	97·9	98·8
8B S. Wales	Coking coal 83·3 Anthracite duff 16·7	Top charge	11·0	24	17½	—	—	91·6	95·9	98·5	99·3
9 S. Yorks.	Coking coal 80·0 Anthracite duff 20·0	Top charge	14·0	27	20	—	—	91·0	93·1	94·8	96·4
10 Westphalia	Not known	Top charge			14	—	—	68·5	88·8	96·4	98·1
11 Westphalia	Not known	Top charge			14	—	—	50·5	82·2	98·2	99·6
12 Durham	Not known	Top charge		Mths.		—	—	95·5	98·4	99·8	99·9
13A S. Yorks.	Parkgate 90·0 Barnsley 10·0	Top charge	11·0	Mths.	20¾	—	—	99·0	99·1	99·4	99·6
13B (*b*) S. Yorks.	Parkgate 80·0 Barnsley hards 20·0	Box test	5·7	28	20¾	18·9	46·4	74·7	88·1	94·4	95·2
13C (*b*) S. Yorks.	Dry dust from Parkgate slack	Box test	4·4	30	20¾	80·6	91·5	94·1	95·1	96·0	96·5
13D (*b*) s. S. Yorks.	Slurry from Parkgate coal	Box test	31·5	45½	20¾	14·2	36·4	60·6	71·5	79·8	88·2

Average Shatter Indices (per cent.).				Density and Porosity.				Analysis (per cent. on air-dried basis).				
On 2 in.	On 1½ in.	On 1 in.	On ½ in.	Apparent S.G.	Real S.G. (ash-free).	Apparent Porosity (per cent.).	Total Porosity (per cent.).	Moisture.	Ash.	Volatile Matter (less moisture).	Sulphur.	Coke No.
93·9	97·2	98·3	98·8	0·89	1·77	46·9	51·3	0·7	8·5	0·4	0·9	1
91·8	96·4	98·0	98·6					0·8	7·8	1·2	1·0	1A
79·4	90·2	95·8	97·8	0·85	1·77		53·8	0·6	9·1	0·7	0·6	2
71·6	86·2	95·0	97·6					1·4	11·4	2·8	0·8	2A
*77·4	*86·3	95·0	98·3	0·94	1·88	30·6	51·6	0·4	12·2	0·2	1·6	3A
69·7	83·0	92·7	97·7	0·91	1·87	43·1	52·3	0·1	5·6	0·7	1·3	3B
54·6	83·6	95·8	97·7	0·78	1·87	46·9	59·2	0·5	5·4	0·9	1·3	3C
68·9	84·8	94·8	97·8	0·80	1·88	40·0	56·2	0·4	5·5	0·9	1·4	3D
48·2	66·4	82·5	92·9	0·98	1·93	34·1	51·5	0·2	16·0	0·5	1·9	3E (I)
51·9	68·1	83·1	93·2	0·96	1·88	36·7	51·5	0·5	15·7	1·7	1·8	3E (II)
56·1	73·1	86·4	95·5	0·98	1·94	41·9	51·5	0·5	14·4	1·9	1·7	3E (III)
69·0	81·9	90·6	97·2	0·89	1·90	44·2	54·8	0·8	12·1	2·5	1·3	3E (IV)
72·3	86·3	94·9	98·3	0·81	1·90	46·6	58·2	0·6	7·0	0·4	1·4	3E (V)
1·6	88·3	96·5	98·6	0·86	1·88	41·1	55·2	0·2	6·0	0·3	1·3	3E (VI)
77·3	89·1	95·4	98·4	0·88	1·91	43·0	54·9	0·2	6·8	0·3	1·4	3E (VII)
79·5	88·5	94·8	98·0	1·02	1·87	30·4	47·4	0·1	11·4	0·3	1·8	3E (VIII)
78·5	90·9	96·8	98·6	0·89	1·88	35·4	54·6	0·2	13·8	0·2	1·3	3F (I)
79·9	91·8	97·4	98·8	0·84	1·88	43·8	56·8	0·1	9·9	0·1	1·4	3F (II)
74·4	84·6	93·4	98·0	0·95		39·6						3F (III)
77·6	88·4	95·1	98·0	0·93	1·90	44·8	53·0	0·1	10·8	0·2	1·5	3F (IV)
75·1	86·1	93·7	97·4	0·99		38·8						3F (III) (*b*)
81·5	91·5	96·6	98·3	0·91		42·7						3F (*b*) s. i.
87·8	92·9	96·2	98·0	0·93		47·2						3F (*b*) s. ii.
78·3	88·2	93·8	96·9	0·96	1·72	35·9	46·4	0·3	9·4	0·9	1·5	3G (I)
71·1	87·4	95·0	96·9	0·88	1·75	40·9	51·6	0·2	9·7	0·9	1·5	3G (II)
68·2	80·0	92·0	97·0	1·02	1·82	34·9	46·3	2·2	11·5	1·7	1·4	4
*71·1	*85·1	94·6	98·4	1·12	1·81	32·0	41·0	0·2	13·1	0·6	1·0	5
85·8	93·2	96·8	98·4	0·87	1·82	39·1	53·7	0·3	8·2	0·6	0·7	6
61·9	77·1	91·9	97·6	0·88	1·81	40·7	52·6	0·8	7·4	1·2	1·3	7
80·2	90·4	96·7	98·5	1·15	1·80	33·6	38·6	0·2	10·6	0·4	1·4	8A
82·8	92·0	97·0	98·3	1·08	1·84	35·1	43·5	0·2	11·0	0·6	1·3	8B
86·0	89·5	92·6	95·5	0·86	1·75	40·3	53·2	1·4	11·7	1·2	1·2	9
89·2	95·7	98·2	99·1	0·88	1·84	37·6	53·7	0·4	9·4	1·1	1·1	10
*88·1	*95·7	98·3	99·0	0·98	1·80	38·9	47·6	0·5	9·6	1·0	1·2	11
*52·6	*71·2	91·1	96·4	1·00	1·92	44·1	50·0	0·3	12·9	0·7	0·9	12
*77·1	*83·9	92·9	97·6	0·93	1·79	45·4	50·0	1·1	10·2	1·9	1·3	13A
67·7	80·4	92·4	96·1	0·97	1·68	33·8	43·2	4·1	7·7	3·3	1·2	13B (*b*)
89·1	93·3	95·2	96·7	0·94	1·76	37·6	51·0	1·6	21·5	2·8	2·0	13C (*b*)
61·6	76·6	86 1	92·3	0·86	1·64	49·8	51·4	1·9	15·0	1·3	1·0	13D (*b*) s.

Coke No. and District.	Coke Data.					Average Size Analysis (per cent.).					
	Detail of Coals used.	Method of Charging.	Moisture in Coal (per cent.).	Coking Time (hr.).	Oven Width (in.).	On 4 in.	On 3 in.	On 2 in.	On 1½ in.	On 1 in.	On ½ in.
13E (I) S. Yorks.	Parkgate and Barnsley. Normal crushing	Top charge	10·5	28	20¾	20·9	44·4	74·4	88·1	—	—
13E (II) S. Yorks.	Parkgate and Barnsley. Uncrushed	Top charge	10·5	28½	20¾	14·4	38·0	72·6	89·8	—	—
13F i. S. Yorks.	Parkgate and Barnsley slack 87, Parkgate dust 13	Top charge	10·4	28	20¾	26·2	54·3	80·2	92·6	—	—
13F ii. S. Yorks.	Parkgate and Barnsley slack 86, Parkgate dust 14	Top charge	10·6	26	20¾	12·8	44·4	77·0	91·0	—	—
13F iii. S. Yorks.	Parkgate and Barnsley slack 84, Parkgate dust 16	Top charge	9·6	28	20¾	30·2	59·7	83·2	92·8	—	—
13F iv. S. Yorks.	Parkgate and Barnsley slack 78, Parkgate dust 22	Top charge	9·0	28¼	20¾	29·7	58·8	84·7	93·3	—	—
13E (*b*) S. Yorks.	Parkgate and Barnsley (83·0) (17·0)	Box test		24		65·3	84·3	94·4	96·8	98·5	99·0
13F (*b*) i. S. Yorks.	5% Parkgate dust blended with Parkgate (83) and Barnsley (17) slack	Box test		24		62·8	78·9	88·3	91·2	94·4	96·6
13F (*b*) ii. S. Yorks.	10%	Box test		24		71·1	84·0	90·0	92·3	93·8	95·7
13F (*b*) iii. S. Yorks.	20%	Box test		24		66·6	80·9	90·0	91·8	93·4	95·7
13F (*b*) iv. S. Yorks.	33⅓%	Box test		24		94·7	95·7	97·9	98·2	98·7	99·0
13F (*b*) v. S. Yorks.	50%	Box test		24		90·2	96·3	98·2	98·8	99·0	99·2
13G (*b*) i. S. Yorks.	1% Fusain, thro' 200 mesh, screened at plant and blended with washed, crushed, Parkgate coal	Box test				70·1	83·1	92·9	95·0	96·8	98·1
13G (*b*) ii. S. Yorks.	2%	Box test				63·3	81·7	91·6	94·1	96·1	97·9
13G (*b*) iii. S. Yorks.	3%	Box test				57·1	86·4	93·9	95·9	97·3	98·3
13G (*b*) iv. S. Yorks.	4%	Box test				84·1	87·7	95·5	97·1	98·3	99·0
13G (*b*) v. S. Yorks.	5%	Box test				78·6	89·3	96·9	97·6	98·5	99·1
13H (*b*) S. Yorks.	Parkgate coal, used for above fusain blends	Box test				49·2	84·4	94·9	97·1	98·2	99·2
13G (*b*) v. r. S. Yorks.	5% Fusain, ground thro' 200 mesh in ball mill, blended with Parkgate coal	Box test				56·9	75·4	92·5	95·3	96·7	98·0
13G (*b*) vi. S. Yorks.	7½%	Box test				65·0	84·3	93·2	95·8	97·9	98·7
13G (*b*) vii. S. Yorks.	10%	Box test				78·4	93·9	96·7	97·4	98·1	98·7
13K (*b*) i. S. Yorks.	20% Cyclone dust, blended with Parkgate coal.	Box test				67·3	84·5	92·6	95·7	97·7	98·5
13K (*b*) ii. S. Yorks.	40%	Box test				71·4	85·3	95·5	97·4	98·2	98·6
13H (*b*) r. 2 S. Yorks.	Parkgate coal, used for above five blends	Box test				61·6	80·7	91·9	94·7	97·1	98·4
13I (*b*) i. S. Yorks.	2% Stone dust ground thro' 200 mesh in ball mill	Box test				62·6	79·6	89·2	92·0	94·1	96·7
13I (*b*) ii. S. Yorks.	5%	Box test				71·1	87·9	91·2	93·7	95·4	97·1
13H (*b*) r. 1. S. Yorks.	Parkgate coal, stored 1 month, used for I (*b*) i. and I (*b*) ii.	Box test				62·6	82·0	90·1	94·5	96·6	97·9
13J S. Yorks.	Carbon deposit from oven arch					91·8	93·8	95·7	96·5	97·0	97·6
13G (*b*) v. r. 2. S. Yorks.	5% Fusain, ground thro' 200 mesh in ball mill, and blended with Parkgate coal	Box test				76·6	84·6	92·8	95·2	97·1	98·2
13G (*b*) vi. r. S. Yorks.	7½%	Box test				75·2	85·5	93·3	94·9	97·0	98·3
13G (*b*) viii. S. Yorks.	15%	Box test				62·9	84·8	94·5	95·6	96·8	97·3
13H (*b*) r. 3. S. Yorks.	Parkgate coal, used for above three blends	Box test				68·9	79·0	91·2	95·0	96·9	98·3
13L (*b*) i. S. Yorks.	20% Synthetic dust, 1 pt. fusain < 200 m., 3 pts. coal < 200 m., blended with P. coal	Box test				64·7	83·5	92·7	95·3	96·5	98·2
13L (*b*) ii. S. Yorks.	30%	Box test				52·6	83·8	93·8	96·1	97·6	98·4
13M (*b*) i. S. Yorks.	2% Parkgate coal, thro' 200 mesh in ball mill, blended with Parkgate coal	Box test				51·6	68·8	88·3	93·0	96·4	98·1
13M (*b*) ii. S. Yorks.	4%	Box test				53·3	73·3	89·7	93·6	96·5	98·0
13M (*b*) iii. S. Yorks.	6%	Box test				53·7	78·2	88·8	93·9	96·0	97·8
13M (*b*) iv. S. Yorks.	10%	Box test				41·6	64·2	84·4	90·9	94·5	97·0

Average Shatter Indices (per cent.).				Density and Porosity.				Analysis (per cent. on air-dried basis).				
On 2 in.	On 1½ in.	On 1 in.	On ½ in.	Apparent S.G.	Real S.G. (ash-free).	Apparent Porosity (per cent.).	Total Porosity (per cent.).	Moisture.	Ash.	Volatile Matter (less moisture).	Sulphur.	Coke No.
74·4	88·1	—	—									13E (I)
72·6	89·8	—	—	0·95		35·8						13E (II)
80·2	92·6	—	—	0·91		19·5						13F i.
77·0	91·0	—	—	0·82		24·6						13F ii.
83·1	92·7	—	—	0·87		34·3						13F iii.
84·7	93·3	—	—	0·87		35·4						13F iv.
74·6	87·2	93·8	97·5	0·87		37·8						13E (*b*)
78·8	89·9	96·0	98·2	0·89		39·5						13F (*b*) i.
80·6	89·8	95·0	97·2	0·93		36·2						13F (*b*) ii.
86·0	93·4	96·5	98·2	0·94		39·2						13F (*b*) iii.
88·3	92·2	95·8	97·8	0·94		37·7						13F (*b*) iv.
91·7	95·1	97·1	98·3	0·95		34·5						13F (*b*) v.
79·4	88·3	94·2	97·7	0·86	1·76	42·3	51·0	0·4	9·1	1·1	1·3	13G (*b*) i.
78·7	89·2	94·2	97·7	0·83	1·81	48·2	55·6	0·3	9·5	1·3	1·3	13G (*b*) ii.
81·7	90·3	95·3	97·9	0·87	1·81	45·5	53·5	0·2	9·5	1·3	1·3	13G (*b*) iii
79·4	87·7	94·2	97·4	0·88	1·78	44·4	52·5	0·5	9·2	1·4	1·3	13G (*b*) iv.
83·5	91·0	95·9	98·0	0·86	1·79	46·1	53·6	0·7	9·0	0·9	1·3	13G (*b*) v.
78·7	87·9	94·2	97·7	0·87	1·83	47·2	54·0	0·3	9·6	1·4	1·2	13H (*b*)
79·1	87·9	94·5	97·5	0·91		43·7						13G (*b*) v. r.
77·9	89·3	95·3	97·9	0·92		43·7						13G (*b*) vi.
82·0	91·3	96·2	97·8	0·90		42·6						13G (*b*) vii.
87·8	93·9	97·3	98·3	0·91		44·2						13K (*b*) i.
88·8	94·4	97·2	98·0	0·91		43·7						13K (*b*) ii.
77·3	87·5	93·8	97·6	0·85	1·84	47·3	55·3	0·4	9·7	2·0	1·4	13H (*b*) r. 2.
78·3	88·8	94·6	97·8	0·90	1·79	44·8	51·8	0·6	11·4	2·1	1·3	13I (*b*) i.
80·5	89·0	94·5	97·7	0·91	1·79	44·5	51·8	0·5	14·1	2·1	1·4	13I (*b*) ii.
78·7	88·1	94·4	97·8	0·90		45·0						13H (*b*) r. 1.
89·1	92·0	93·6	95·2	1·51	2·04	17·8	26·3	0·3	2·5	1·8	1·5	13J
78·1	87·0	93·7	97·3	0·84		42·3						13G (*b*) v. r. 2.
76·6	87·0	94·3	97·5	0·89		43·7						13G (*b*) vi. r.
84·5	91·2	95·0	96·6	0·90		42·5						13G (*b*) viii.
75·8	86·1	93·3	97·3	0·88	1·79	39·2	52·7	0·9	10·0	1·6	1·6	13H (*b*) r. 3.
81·6	89·1	94·8	97·2	0·87		33·7						13L (*b*) i.
82·1	91·0	95·7	97·4	0·88	1·77	37·3	51·1	0·5	9·2	1·5	1·6	13L (*b*) ii.
74·1	85·9	94·5	97·4	0·87		40·2						13M (*b*) i.
73·7	87·5	93·6	97·2	0·86		44·1						13M (*b*) ii.
74·2	85·6	93·0	97·2	0·84		37·4						13M (*b*) iii.
76·5	86·0	94·3	97·3	0·85	1·83	39·3	54·8	0·8	7·6	0·8	1·4	13M (*b*) iv

	Coke Data.					Average Size Analysis (per cent.).					
Coke No. and District.	Details of Coals used.	Method of Charging.	Moisture in Coal (per cent.).	Coking Time (hr.).	Oven Width (in.).	On 4 in.	On 3 in.	On 2 in.	On 1½ in.	On 1 in.	On ½ in.
13G (*b*) v. r. 3. S. Yorks.	5% Fusain, ground thro' 200 mesh, blended with P. coal	Box test				65·5	78·2	93·7	96·5	97·9	98·7
13G (*b*) vi. r. 2. S. Yorks.	7½%	Box test				61·1	84·5	91·0	95·0	97·1	98·1
13H (*b*) r. 4. S. Yorks.	Parkgate coal, used in above eight blends	Box test				53·2	73·7	86·9	92·6	95·7	98·0
13N (*b*) i. S. Yorks.	5% Low temp. breeze, ground thro' 200 mesh and Parkgate coal	Box test				79·3	87·0	94·1	95·9	97·7	98·5
13N (*b*) ii. S. Yorks.	7½%	Box test				76·7	87·6	92·9	95·3	97·3	98·3
13O (*b*) (I) i. S. Yorks.	5% Anthracite, thro' 1/16-in., with Parkgate coal	Box test				82·7	88·4	92·9	95·2	97·3	98·4
13O (*b*) (I) ii. S. Yorks.	7½%	Box test				85·8	92·4	94·9	96·0	97·5	98·4
13P (*b*) i. S. Yorks.	2½% Parkgate coke, ground thro' 200 mesh and Parkgate coal	Box test				64·3	78·4	93·8	96·0	97·6	98·5
13P (*b*) ii. S. Yorks.	5%	Box test				80·9	88·8	94·6	96·0	97·7	98·6
13P (*b*) iii. S. Yorks.	7½%	Box test				84·8	91·2	95·0	96·7	97·7	98·4
13Q (*b*) i. t. S. Yorks.	Parkgate durain, < ⅛ in. Top section of box	Box test				56·9	75·2	79·5	80·8	81·4	82·8
13Q (*b*) i. *b*. S. Yorks.	Parkgate durain, < ⅛ in. Bottom section of box	Box test				41·3	80·9	91·3	94·6	95·6	96·7
13H (*b*) r. 5. S. Yorks.	Parkgate coal, wet, used for 13P (*b*) series	Box test				66·8	80·5	91·4	95·6	97·5	98·7
13H (*b*) r. 6. S. Yorks.	Parkgate coal, dry	Box test				56·4	77·8	90·9	94·1	96·6	98·2
13R (*b*) (I) S. Yorks.	5% Fusain, thro' 200 m. 10% P. coal, thro' 200 m.	Box test				57·5	76·6	90·1	94·3	97·4	98·8
13R (*b*) (II) S. Yorks.	5% Fusain, thro' 200 m. 10% P. coal, thro' 40 m.	Box test				69·1	86·2	92·8	96·2	98·2	98·9
13R (*b*) (III) S. Yorks.	5% Fusain, thro' 200 m. 10% P. coal, thro' 1/16 in.	Box test				55·8	83·3	93·9	96·7	98·3	99·1
13R (*b*) (IV) S. Yorks.	5% Fusain, thro' 200 m. 10% P. coal, thro' ⅛ in.	Box test				57·2	81·5	94·2	97·2	98·6	99·2
13G (*b*) ix. S. Yorks.	7½% Fusain, oxidised by standing 1–3 months	Box test				65·2	88·9	96·4	97·8	98·6	99·0
13H (*b*) r. 7. S. Yorks.	Parkgate coal used in above five blends	Box test				52·5	70·0	87·1	92·0	96·3	98·4
14 S. Wales	Steam coal 50·0 House coal 50·0	Top charge	10·0	28	17½	—	—	89·1	96·6	98·4	99·0
15 Derby.	Black shale 45·0 Tupton 45·0 Deep hard 10·0	Cake charge	11·5	50	24	17·9	48·5	78·6	91·3	96·6	98·8
16 Lancs.	Arley 46·0, 4-Ft. 16·0 King 30·0, Yard 8·0	Cake charge	10·0	24	16	38·0	70·7	87·2	93·2	96·9	98·4
17A S. Yorks.	Parkgate 53·0 Silkstone 27·0 Barnsley 20·0	Top charge	11·6	30–32	20	59·8	79·7	90·9	94·6	97·1	98·2
17B S. Yorks.		Cake charge	11·2	34–35	20	41·8	64·7	83·3	91·6	97·2	98·7
17C S. Yorks.	A. Parkgate hards 100 (crushed)	Top charge	10·4	33–35	20	70·8	86·4	92·7	94·1	96·1	97·2
17D S. Yorks.	R. Barnsley hards 100 (crushed)	Top charge	9·0	30–33	20	82·9	88·2	93·0	94·5	95·8	96·7
17E S. Yorks.	A. Swallow Wood softs 100·0	Top charge	9·0	28–30	20	46·1	66·4	82·4	87·8	94·3	97·3
17F S. Yorks.	A. Swallow Wood hards 100·0 (crushed)	Top charge	10·8	39–42	20	65·9	78·2	86·4	90·2	94·2	96·6
17G S. Yorks.	A. Parkgate softs 100	Top charge	8·7	36–38	20	67·4	84·8	93·1	95·7	97·8	98·8
17H S. Yorks.	R. Barnsley softs 100	Top charge	11·0	29–31	20	56·4	77·8	90·6	94·2	97·0	98·2
17I S. Yorks.	R. Silkstone softs 100	Top charge	9·6	38–40	20	73·5	81·9	89·9	93·2	96·4	98·4
17J S. Yorks.	Parkgate 75·0 Swallow Wood 25·0 } A.	Cake charge	10·4	43–48	20	68·7	87·4	94·8	97·0	98·5	99·1
17J (*b*) S. Yorks.	Ditto	Bag test				64·8	81·4	94·6	97·7	99·1	99·3
17K S. Yorks.	R. Parkgate softs 100·0	Top charge	10·0	29	20	68·9	87·0	95·0	97·0	98·4	99·0
17K (*b*) S. Yorks.	Ditto	Bag test				74·2	84·0	92·8	96·3	98·5	98·9
17H (*b*) S. Yorks.	R. Barnsley softs	Bag test				88·2	92·2	96·7	98·0	99·0	99·4
17I (*b*) S. Yorks.	R. Silkstone softs	Bag test				53·9	79·3	89·9	93·5	96·9	98·4
17H (*b*) s. S. Yorks.	Slurry from R. Barnsley	Bag test				79·5	92·6	97·5	98·4	98·8	99·0
17K (*b*) s. S. Yorks.	Slurry from R. Parkgate	Bag test				87·0	94·4	97·9	98·8	99·2	99·4

Average Shatter Indices (per cent.).				Density and Porosity.				Analysis (per cent. on air-dried basis).				Coke No.
On 2 in.	On 1½ in.	On 1 in.	On ½ in.	Apparent S.G.	Real S.G. (ash-free).	Apparent Porosity (per cent.).	Total Porosity (per cent.).	Moisture.	Ash.	Volatile Matter (less moisture).	Sulphur.	
77·3	87·8	94·3	97·4	0·89		37·8						13G (*b*) v. r. 3.
77·4	90·2	94·7	97·6	0·90		43·5						13G (*b*) vi. r. 2.
77·1	86·0	93·5	97·2	0·92	1·81	35·3	50·8	0·6	8·7	1·0	1·4	13H (*b*) r. 4.
77·8	86·6	93·7	96·8	0·88		38·4						13N (*b*) i.
75·9	85·4	92·5	96·1	0·89		43·6						13N (*b*) ii.
77·7	83·7	91·2	96·2	0·86		37·2						13O (*b*) i.
78·7	86·7	92·1	96·6	0·90		33·7						13O (*b*) ii.
78·2	89·4	95·2	97·7	0·85		38·5						13P (*b*) i.
86·6	90·3	94·9	97·2	0·88		36·9						13P (*b*) ii.
86·6	91·2	95·1	97·5	0·89	1·80	34·8	52·1	0·5	8·2	1·5	1·5	13P (*b*) iii.
79·9	83·1	84·8	86·3	0·94	1·83	34·4	50·0	0·4	7·2	0·8	0·5	13Q (*b*) i. t.
86·3	92·9	96·5	97·5	1·18	1·85	26·3	37·6	0·5	6·3	0·8	0·6	13Q (*b*) i. *b*.
72·8	86·7	93·6	97·3	0·87	1·81	36·6	53·2	0·3	7·0	1·1	1·4	13H (*b*) r. 5.
72·8	86·8	94·4	97·8	0·89		32·6						13H (*b*) r. 6.
70·9	85·3	93·8	98·0	0·88		37·1						13R (*b*) (I)
69·4	83·8	93·2	97·8	0·80		34·8						13R (*b*) (II)
74·1	85·6	93·9	97·4	0·85		34·8						13R (*b*) (III)
76·0	86·4	93·5	97·2	0·89		36·6						13R (*b*) (IV)
79·5	89·4	95·3	97·4	0·90		41·8						13G (*b*) ix.
64·2	81·7	91·5	97·0	0·88	1·78	39·9	52·2	0·3	8·1	1·0	1·2	13H (*b*) r. 7.
87·5	95·8	98·2	98·9	0·92	1·81	39·1	50·8	1·0	8·5	1·0	1·2	14
52·0	66·3	83·3	96·6	0·94	1·73	33·5	48·0	3·9	10·5	2·2	1·8	15
67·5	82·8	92·2	97·7	0·91	1·87	35·4	53·1	0·3	10·7	0·6	1·5	16
81·6	90·0	94·9	97·9	0·94	1·88	45·1	51·5	0·6	9·5	0·5	1·4	17A
*65·3	*81·6	92·3	98·3	1·04	1·85	37·8	45·8	0·3	10·2	0·4	1·4	17B
76·7	85·0	92·6	97·0	0·96	1·77	33·2	46·6	1·6	4·1	1·5	0·5	17C
81·2	85·8	92·8	95·9	0·90	1·70	36·1	48·6	3·4	6·5	3·0	0·9	17D
63·6	72·5	86·7	96·4	0·74	1·71	47·6	58·0	1·9	6·0	2·3	1·2	17E
*59·2	*70·1	85·9	95·1	0·90	1·76	40·6	50·2	1·1	6·8	1·1	1·0	17F
71·2	81·7	93·2	97·3	0·81	1·81	39·9	56·2	0·7	6·2	0·8	1·5	17G
69·1	79·0	92·1	96·9	0·77	1·75	50·5	57·2	1·8	7·2	2·0	1·7	17H
62·2	73·4	87·6	95·6	0·88	1·91	41·1	56·1	0·4	15·6	1·9	1·6	17I
67·2	81·6	93·0	97·9	1·01	1·76	35·1	44·8	0·8	9·8	1·0	1·4	17J
74·4	86·2	94·5	98·1	0·92	1·83	43·2	51·6	0·5	9·9	1·6	1·4	17J (*b*)
78·9	88·6	94·9	98·1	1·00	1·83	35·0	46·8	0·4	7·7	1·6	1·5	17K
81·0	88·8	95·5	97·7	0·86	1·85	37·1	54·5	0·3	6·6	0·7	1·3	17K (*b*)
81·0	84·0	93·0	96·8	0·86	1·74	45·4	52·2	0·8	8·1	0·8	1·1	17H (*b*)
66·1	75·4	89·1	96·6	0·97	1·89	41·8	49·4	0·2	5·0	0·8	1·1	17I (*b*)
87·4	93·4	97·0	98·4	0·87		46·0						17H (*b*) s.
85·7	93·0	97·0	98·6	0·96		42·6						17K (*b*) s.

Coke No. and District.	Coke Data.					Average Size Analysis (per cent.).					
	Details of Coals used.	Method of Charging.	Moisture in Coal (per cent.).	Coking Time (hr.).	Oven Width (in.).	On 4 in.	On 3 in.	On 2 in.	On 1½ in.	On 1 in.	On ½ in.
17L S. Yorks.	Parkgate 80·0 Barnsley 20·0 R.	Cake charge				51·5	82·7	94·1	96·6	98·1	99·0
17M S. Yorks.	Retort carbon					—	—	—	—	—	—
17JL S. Yorks.	Parkgate Barnsley Swallow Wood	Cake charge	10·0	45	20	30·5	55·7	78·2	88·3	95·0	—
18A S. Yorks.	Thorncliffe 58·6 Flockton 41·4	Top charge	9·0	12	14	31·6	56·5	82·1	91·3	96·3	98·1
18B S. Yorks.		Cake charge	8·0	24	21	26·4	49·5	77·6	90·9	97·0	98·4
18C S. Yorks.		Cake charge	10·4	36	20	28·6	51·6	81·3	92·6	97·5	99·1
18D S. Yorks.		Top charge	10·2	24	20	38·0	66·8	91·9	97·0	98·6	99·3
18E S. Yorks.		Top charge	12·4	32½	20	43·8	75·2	92·9	96·0	98·1	99·0
18F S. Yorks.		Top charge	12·4	19¼	18	3·1	23·4	63·8	83·4	94·4	97·3
18G S. Yorks.		Cake charge	12·4	21½	18	0·7	19·0	59·2	86·5	97·7	99·3
18H S. Yorks.	18A slack 89·8 Barnsley 10·2	Top charge	10·0	34½	20	30·6	69·0	88·3	95·0	98·3	99·1
18I S. Yorks.	18A slack 73·1 Barnsley 26·9	Top charge	11·4	34	20	44·5	79·4	90·4	94·8	97·7	98·7
18J S. Yorks.	18A slack 67·8 Barnsley 32·2	Top charge	11·0	34	20	17·3	62·3	90·6	96·0	97·9	98·7
18K S. Yorks.	18A slack 56·7 Barnsley 43·3	Top charge	11·4	33½	20	48·4	78·5	90·4	95·9	97·8	98·5
18L S. Yorks.	18A slack 80·0 Barnsley 20·0	Top charge	11·0	13	14	0·6	13·5	74·0	90·0	96·4	98·4
19A S. Yorks.	Barnsley Haigh Moor	Top charge	12·0	12	14	1·5	7·5	35·3	66·9	91·9	98·1
19B S. Yorks.	Parkgate 100	Top charge	12·0	12	14	0·0	11·5	48·7	81·5	95·1	98·0
19C S. Yorks.	Parkgate Barnsley Haigh Moor	Top charge	12·0	12	14	0·0	6·7	32·4	64·6	89·2	97·1
20A Cumb.	Six Quarter 70·0 Little Main 17·0 Four Foot 13·0	Top charge	8·2	24	20½	50·7	70·8	89·6	94·6	97·0	98·2
20B Cumb.		Cake charge	8·2	28	20½	52·0	73·8	88·1	94·0	97·1	98·6
21A Cumb.	Six Quarter Bottoms 40·0 Six Quarter Tops 35·0 Main Band 25·0	Top charge	8·5	25	20½	19·7	48·2	73·6	87·1	94·0	97·7
21B Cumb.		Cake charge	9·3	28	20½	13·1	39·7	67·3	85·1	94·5	98·0
22A Derby.	Deep Soft 70·0 Barnsley 30·0	Cake charge	10·2	31	20½	22·8	51·6	79·8	92·8	97·2	98·9
22B Derby.		Cake charge	10·2	28¾	21	19·2	50·9	79·8	92·4	97·7	99·2
22C Derby.		Cake charge	10·6	24	21	5·2	29·7	62·7	84·5	94·8	99·0
22D Derby.	Deep Soft 100	Cake charge	10·5	30½	20½	2·7	16·1	56·7	88·5	97·5	99·2
22E Derby.		Cake charge	10·5	24	21	7·0	27·0	63·7	86·8	95·8	98·3
22F Derby.	Coking slack 100	Cake charge	10·0	34	20¾	18·7	31·5	62·0	78·6	90·1	95·6
22G Derby.	Coking slack 80·0 Low temp. breeze 20·0	Cake charge	10·0	34	20¾	66·3	79·5	85·3	88·9	92·7	96·2
22H Derby.	Deep Soft 55·0 Ell 30·0 Black Shale 10·0 Waterloo 5·0	Cake charge	10·5	26	20½	3·0	20·3	61·5	84·3	95·1	98·7
22I Derby.		Top charge	10·0	21½	18	3·0	26·6	79·5	94·1	97·9	98·8
22J Derby.		Top charge	9·2	18	18	4·0	19·5	64·9	83·5	92·4	97·2
22K Derby.		Top charge	10·3	13	14	6·8	33·1	81·0	91·2	95·8	98·2
22L. t Derby.	Deep Soft Ell Black Shale Waterloo	Top charge	10·0	26½	20¾	17·0	41·0	71·0	80·3	86·9	90·6
22L. m Derby.						7·3	37·8	73·6	85·2	91·7	94·7
22L. b Derby.						7·5	29·5	66·2	81·2	91·1	95·6
22M. t Derby.		Cake charge	10·0	27¼	20¾	9·6	33·2	66·9	80·1	89·1	93·7
22M. m Derby.						2·1	14·2	55·0	75·6	89·6	96·2
22M. b Derby.						3·9	16·9	52·3	74·3	90·3	96·8

Average Shatter Indices (per cent.).				Density and Porosity.				Analysis (per cent. on air-dried basis).				Coke No.
On 2 in.	On 1½ in.	On 1 in.	On ½ in.	Apparent S.G.	Real S.G. (ash-free).	Apparent Porosity (per cent.).	Total Porosity (per cent.).	Moisture.	Ash.	Volatile Matter (less moisture).	Sulphur.	
73·2	85·2	95·0	98·3	1·03	1·82	35·8	45·5	0·2	8·9	1·1	1·3	17L
93·9	96·4	97·4	98·3	1·79	2·07	12·2	14·7	0·2	2·5	0·8	1·6	17M
70·4	82·1	93·1	97·9									17JL
70·8	80·2	91·3	96·5	0·79	1·86	48·5	58·9	1·8	9·5	2·1	1·7	18A
62·9	83·6	93·3	97·8	0·92	1·85	40·3	51·3	0·4	9·5	1·1	1·6	18B
61·6	77·4	89·9	97·6	0·93	1·81	42·9	50·3	0·3	8·8	0·6	1·6	18C
68·1	83·0	91·8	97·7	0·85	1·76	42·9	53·6	0·8	9·2	1·0	1·8	18D
75·2	83·9	92·3	97·7	0·84	1·76	45·8	54·4	0·3	11·1	0·5	1·7	18E
*78·5	*88·6	94·7	98·2	0·83	1·80	46·3	55·6	1·0	11·1	0·9	1·7	18F
*60·7	*79·2	92·6	98·2	0·92	1·80	28·5	50·9	1·0	10·4	1·1	1·7	18G
72·4	84·9	93·7	98·0	0·86	1·82	32·4	54·2	0·5	8·4	0·7	1·5	18H
*70·6	*80·6	91·4	97·3	0·88	1·79	41·2	52·9	0·6	11·4	1·1	1·7	18I
72·6	83·8	92·4	97·8	0·91	1·77	44·1	50·5	0·5	10·1	1·0	1·6	18J
70·2	82·2	91·8	96·7	0·84	1·70	30·1	52·8	0·5	10·0	1·1	1·4	18K
68·9	86·6	94·8	98·1	0·90	1·83	41·6	52·3	0·8	9·8	0·9	1·8	18L
73·4	83·9	93·2	97·9	0·91	1·81	28·7	51·0	1·3	7·9	1·7	1·2	19A
67·9	82·0	93·0	97·8	0·82	1·84	44·9	54·0	0·9	5·4	1·4	1·1	19B
65·2	80·7	92·4	97·8	0·77	1·80	45·5	58·4	0·8	7·8	1·5	1·1	19C
74·8	87·7	93·5	97·7	0·87	1·90	39·2	55·5	0·2	7·7	0·2	1·1	20A
66·9	79·7	90·6	97·2	0·93	1·83	34·9	50·8	0·4	9·8	0·3	1·2	20B
60·8	76·6	89·6	96·8	0·95	1·91	36·8	51·8	0·2	9·9	0·3	1·5	21A
52·7	74·9	88·2	96·9	0·94	1·86	36·7	51·0	0·4	9·5	0·3	1·6	21B
63·4	77·5	90·5	97·6	0·94		41·1		—				22A
47·9	66·4	86·7	97·5	0·95	1·76	29·8	48·0	0·7	9·8	1·1	1·3	22B
33·9	59·0	82·1	97·2	0·89	1·75	36·7	50·8	2·6	8·1	2·5	1·6	22C
42·3	66·6	85·7	97·2	0·91	1·75	36·7	49·7	0·6	8·5	1·1	1·6	22D
*40·4	*61·3	80·9	96·5	0·94		39·8		—				22E
62·2	74·3	87·4	96·9	0·85	1·73	40·7	52·7	1·1	9·0	1·5	1·6	22F
71·9	78·8	87·0	94·6	0·89	1·72	42·6	50·6	1·0	10·1	2·0	1·8	22G
*59·3	*77·0	88·9	97·4	0·94	1·75	37·1	48·8	0·6	10·4	1·3	1·7	22H
67·8	84·4	93·6	97·8	0·85	1·75	41·2	53·6	1·2	10·1	1·8	1·6	22I
*56·8	*74·9	86·3	96·8	0·81	1·77	41·2	56·0	2·0	10·0	2·8	1·7	22J
58·0	74·1	86·8	96·1	0·83	1·73	41·6	53·8	3·3	8·0	2·4	1·6	22K
72·1	85·0	92·7	96·4	0·83	1·72	40·9	53·6	0·4	8·7	0·6	1·6	22L. t
70·6	85·3	92·9	96·9									22L. m
47·3	72·0	88·7	97·2	0·88	1·74	45·3	51·1	0·3	8·4	0·8	1·5	22L. b
59·3	75·8	88·9	96·8	0·90	1·71	34·9	49·2	1·9	8·2	0·7	1·3	22M. t
45·1	67·1	85·1	97·0	0·88	1·71	41·5	50·3	1·2	7·6	1·7	1·3	22M. m
34·2	61·2	84·9	97·2	0·99	1·74	36·3	45·9	0·6	9·4	1·2	1·5	22M. b

Coke No. and District.	Coke Data.					Average Size Analysis (per cent.).					
	Details of Coals used.	Method of Charging.	Moisture in Coal (per cent.).	Coking Time (hr.).	Oven Width (in.).	On 4 in.	On 3 in.	On 2 in.	On 1½ in.	On 1 in.	On ½ in.
22N. t Derby.	Deep Soft Ell Black Shale Waterloo	Cake charge	10·0	28½	21	4·8	23·2	62·8	79·6	91·9	96·9
22N. m Derby.						5·2	22·6	65·4	83·8	93·4	97·4
22N. b Derby.						0·5	13·1	50·2	74·2	91·0	96·8
22P (*b*) i. Derby.	2% Parkgate cyclone dust (25% fusain) blended with slack, 22O (*b*)	Box test		28¾		37·8	60·5	82·7	89·4	92·9	96·1
22P (*b*) ii. Derby.	4%	Box test		30¼		55·9	78·0	91·7	94·9	97·4	98·6
22P (*b*) iii. Derby.	8%	Box test		47½		76·0	82·3	88·0	90·4	92·1	94·5
22P (*b*) iv. Derby.	12%	Box test		24¾		75·7	89·0	95·6	97·4	98·3	98·7
22P (*b*) v. Derby.	16%	Box test		29¼		65·6	84·3	91·7	93·1	94·5	96·4
22O (*b*) Derby.	Slack used in above series	Box test		26¼		30·4	55·5	79·7	86·8	91·7	95·0
22P i. Derby.	3% Parkgate dust 97% slack 22O (*b*) r. 1.	Top charge	7·0	24	20¾	16·1	47·0	83·3	92·4	97·2	98·2
22P iv. t. Derby.	12% Parkgate dust blended with slack 22O (*b*) r. 1.	Top charge	5·0	24	20¾	20·0	51·3	80·3	87·9	90·4	92·7
22P iv. m. Derby.	12%					27·5	57·3	88·9	94·6	96·7	97·8
22P iv. b. Derby.	12%					10·1	41·3	76·4	88·4	95·5	97·7
22Q (*b*) i. Derby.	3% Parkgate and thro' 200 mesh, and slack 22O (*b*) r. 1.	Box test		31½		73·5	85·9	93·4	95·3	97·0	98·0
22Q (*b*) ii. Derby.	6%	Box test		39¾		62·7	81·4	90·6	94·4	96·5	97·8
22Q (*b*) iii. Derby.	9%	Box test		34¾		45·8	66·6	81·3	87·4	91·1	94·7
22O (*b*) r. 1. Derby.	Fresh slack used in above 3 blends	Box test		31		54·7	73·8	87·1	91·3	93·9	96·3
22R (*b*) i. Derby.	1% Low temp. breeze, ground thro' 200 mesh, and slack 22O (*b*) r. 2.	Box test		29		46·7	67·5	82·8	89·9	94·9	97·0
22R (*b*) ii. Derby.	2%	Box test		29¾		71·4	81·7	89·0	92·2	94·6	97·0
22R (*b*) iii. Derby.	3%	Box test		29½		82·5	87·1	93·4	95·5	96·9	98·2
22O (*b*) r. 2. Derby.	Slack, used in above 3 blends, standing 14 days	Box test		28½		69·1	78·8	90·0	93·1	94·9	97·3
22S (*b*) i. Derby.	2% H.T. coke (No. 22) ground thro' 200 mesh and slack 22O (*b*) r. 4.	Box test		28½		80·7	89·7	93·7	95·7	96·8	97·3
22S (*b*) ii. Derby.	3%	Box test		28½		66·9	84·4	90·6	93·4	94·8	97·1
22T (*b*) i. Derby.	3% Stone dust thro' 200 mesh, and slack 22O (*b*) r. 4.	Box test		28½		70·9	89·0	95·2	96·7	97·4	98·5
22O (*b*) r. 4. Derby.	Slack for above 3 tests—fresh	Box test		28¼		79·9	87·4	91·6	93·2	94·6	96·5
22O (*b*) r. 3. Derby.	Slack 22O (*b*) r. 1. standing 1 month	Box test		29		69·7	86·8	92·4	96·1	97·0	98·0
23A Durham	Brockwell Hutton Busty	Top charge	2·5	26	21	21·8	56·7	82·0	91·5	95·2	97·4
23B S. Yorks.	Silkstone 46, Barnsley 20, Silk. 4 ft. 15·4, Parkgate 9·3, Thorncliffe 9·3	Cake charge	10·0	46½	21	40·5	61·8	80·9	91·9	97·0	98·9
24 Kent	No. 5, 100	Top charge	9·0	13	14	1·0	9·5	47·2	77·0	91·6	95·7
25A S. Wales	Anthracite 66·7 Coegnant 33·3	Cake charge	12·0	36	21	1·7	9·4	40·5	73·8	92·1	96·3
25B S. Wales	Anthracite duff 33·0 Cribbwr Fawr 33·0 Steam coal 33·0	Cake charge	10·0	19–24	19	4·7	17·7	57·0	90·6	97·7	98·3
26A S. Yorks.	Haigh Moor 75·0 Lidgett 10·0 Kent thick 8·0 Barnsley 7·0	Top charge	1·0	26½	20	51·1	68·8	79·4	85·8	91·8	97·2
26B S. Yorks.		Top charge	13·0	36	20	41·6	66·8	85·4	92·5	96·5	98·7
26C S. Yorks.		Top charge			20	29·9	51·0	72·3	82·8	91·8	—
27A S. Yorks.	Parkgate hards (lumps) 100	Top charge	4·0	72	Beehive	19·5	39·3	56·6	76·2	90·0	95·5
27B S. Yorks.	Barnsley hards (lumps) 100	Top charge	4·0	27½	20	11·2	33·4	73·6	90·3	97·5	98·9
28A Derby.	Black Shale 100	Cake charge	14·8	34½	20	27·1	45·2	75·7	86·0	93·4	98·0
28B Derby.	Tupton 100	Cake charge	12·5	32½	20	14·5	37·6	85·3	91·9	96·5	98·8
28C Derby.	Deep Hard 100	Cake charge	16·3	36¾	20	77·8	86·4	91·1	93·1	95·5	97·2

Average Shatter Indices (per cent.).				Density and Porosity.				Analysis (per cent. on air-dried basis).				
On 2 in.	On 1½ in.	On 1 in.	On ½ in.	Apparent S.G.	Real S.G. (ash-free).	Apparent Porosity (per cent.).	Total Porosity (per cent.).	Moisture.	Ash.	Volatile Matter (less moisture).	Sulphur.	Coke No.
58·6	77·4	90·2	97·6	0·90	1·76	44·8	50·3	0·3	7·6	0·9	1·4	22N. t
54·8	75·2	89·0	97·3	0·92	1·76	40·6	49·4	0·5	7·7	0·9	1·3	22N. m
38·4	64·6	86·4	97·1	0·98	1·79	38·9	54·4	0·4	8·4	1·0	1·4	22N. b
68·0	84·9	94·0	97·9	0·90		33·4						22P (*b*) i.
74·0	87·9	94·8	98·1	0·85		33·9						22P (*b*) ii.
76·7	87·7	95·0	97·5	0·85		36·2						22P (*b*) iii.
78·4	90·0	95·6	97·7	0·84	1·76	44·7	54·4	0·5	10·7	0·8	1·5	22P (*b*) iv.
78·9	90·1	95·8	97·8	0·84		33·6						22P (*b*) v.
71·6	85·3	93·3	97·8	0·81		43·2						22O (*b*)
60·6	80·7	92·3	97·6	0·81		42·5						22P i.
76·7	90·3	95·4	97·1	0·84	1·79	43·7	55·3	1·8	12·4	1·2	1·7	22P iv. t.
79·7	90·7	96·2	98·1	0·82	1·82	43·5	57·1	0·7	13·6	0·9	1·8	22P iv. m.
67·1	83·9	94·7	98·2	0·91	1·85	40·1	52·7	0·5	11·2	0·7	1·7	22P iv. b.
73·5	84·1	92·9	97·7	0·81		45·9						22Q (*b*) i.
72·0	84·3	92·8	97·5	0·81		45·9						22Q (*b*) ii.
71·3	83·5	92·1	97·2	0·80		43·9						22O (*b*) iii.
69·2	80·6	90·6	97·4	0·79		41·6						22O (*b*) r. i.
63·6	77·7	90·4	96·9	0·84		44·0						22R (*b*) i.
69·6	84·7	92·6	97·2	0·80		45·6						22R (*b*) ii.
69·2	84·7	93·6	97·5	0·86		41·4						22R (*b*) iii.
70·4	82·3	92·6	97·6	0·88		37·6						22O (*b*) r. 2.
74·6	83·9	92·7	96·7	0·85		42·1						22S (*b*) i.
80·2	88·8	94·7	97·7	0·85		43·8						22S (*b*) ii.
79·6	89·5	95·5	97·9	0·83		43·7						22T (*b*) i.
80·7	88·3	94·0	97·2	0·84	1·73	39·8	54·1	1·8	12·6	1·4	1·6	22O (*b*) r. 4.
63·5	80·0	91·3	97·6	0·81	1·73	42·1	56·0	0·6	14·5	0·9	1·7	22O (*b*) r. 3.
80·9	90·6	94·9	98·0	0·99	1·86	44·0	48·2	0·6	7·7	1·1	0·9	23A
47·9	69·4	87·2	97·4	1·02	1·93	39·6	48·8	0·2	10·8	0·7	2·0	23B
*67·7	*87·9	96·9	98·4	0·95	1·87	42·8	50·8	0·4	9·8	0·8	0·7	24
*58·6	*83·5	93·3	97·1	1·08	1·76	35·1	40·0	3·8	5·0	1·6	0·7	25A
69·5	86·9	95·9	97·6	1·18	1·79	33·0	35·9	0·6	6·3	2·7	1·0	25B
*65·6	*71·1	81·2	94·3	0·85	1·79	40·4	54·4	0·9	9·3	1·5	1·3	26A
63·9	76·4	88·6	97·1	0·90	1·82	42·5	52·0	1·1	6·9	0·3	1·0	26B
*70·3	*81·7	91·0	96·9									26C
*68·3	*80·5	90·5	97·0	1·05	1·82	34·6	43·3	0·8	3·0	0·9	0·6	27A
65·4	80·4	91·3	97·0	1·10	1·74	29·6	37·9	1·6	3·0	1·7	0·5	27B
60·9	67·3	80·3	95·6	0·93	1·78	36·5	49·7	0·6	10·7	0·8	1·9	28A
62·7	72·2	86·8	97·4	0·90	1·80	37·8	51·3	0·2	7·5	0·6	1·5	28B
80·4	85·3	90·2	95·9	0·97	1·72	34·1	47·0	2·1	13·9	1·5	1·3	28C

Coke No. and District.	Coke Data.					Average Size Analysis (per cent.).					
	Details of Coals used.	Method of Charging.	Moisture in Coal (per cent.).	Coking Time (hr.).	Oven Width (in.).	On 4 in.	On 3 in.	On 2 in.	On 1½ in.	On 1 in.	On ½ in.
28D Derby.	Deep Soft 100	Cake charge	19·6	35½	20	25·9	53·0	77·6	85·0	93·3	97·7
28E Derby.	Waterloo 100	Cake charge	18·4	35	20	27·7	61·8	82·4	90·6	95·2	97·7
28F Derby.	Black Shale Tupton	Cake charge			20	29·4	53·1	75·2	84·2	92·5	97·6
29A S. Yorks.	Parkgate and Silkstone	Cake charge	10·0	25¾	21	14·6	35·4	75·1	85·9	94·6	97·6
29B S. Yorks.		Top charge	10·0	22½	21	13·7	42·0	78·5	89·0	95·2	97·2
29C S. Yorks.		Top charge	12·0	12	14	6·5	31·9	82·2	93·5	97·3	98·1
29D S. Yorks.	Wath Wood and Swallow Wood	Top charge	8·5	22½	21	14·4	36·6	71·1	84·0	93·4	97·0
29E S. Yorks.		Top charge	9·0	13	14	3·1	18·5	62·4	80·3	91·7	96·7
29F S. Yorks.	Parkgate and Silkstone 80·0 Wath Wood and Swallow Wood 20·0	Top charge	8·5	24	21	17·7	38·4	71·8	85·0	94·4	97·2
G S. Yorks.		Top charge	9·0	12¼	14	1·3	11·9	58·1	81·2	93·1	96·8
29H S. Yorks.	Sampled at blast furnaces.					15·2	34·6	64·9	78·5	89·3	—
29I (*b*) i. S. Yorks.	P. and S. slack 95 Low temp. breeze 5	Box test				—	—	64·3	75·2	—	—
29I (*b*) ii. S. Yorks.	P. and S. slack 90 Low temp. breeze 10	Box test				—	—	72·6	80·7	—	—
29I (*b*) iii. S. Yorks.	P. and S. slack 85 Low temp. breeze 15	Box test				—	—	61·5	67·4	—	—
29I (*b*) iv. S. Yorks.	P. and S. slack 80 Low temp. breeze 20	Box test				—	—	81·4	86·6	—	—
29I (*b*) v. S. Yorks.	P. and S. slack 70 Low temp. breeze 30	Box test				77·5	78·0	82·2	84·6	87·9	92·5
29I (*b*) vi. S. Yorks.	P. and S. slack 60 Low temp. breeze 40	Box test		24		76·4	80·8	82·7	85·9	91·1	94·6
29J S. Yorks.	P. and S. slack 80 Low temp. breeze 20	Top charge	9·0	14¼	21	39·1	61·5	81·2	88·8	93·4	95·6
29K S. Yorks.		Top charge	9·0	10	14	39·7	64·1	83·0	89·5	93·3	95·1
29L (*b*) i. S. Yorks.	P. and S. slack 90 Anthracite duff 10	Box test				31·1	46·3	64·9	74·2	83·8	92·0
29L (*b*) ii. S. Yorks.	P. and S. slack 80 Anthracite duff 20	Box test				—	—	94·0	95·3	—	—
29L (*b*) iii. S. Yorks.	P. and S. slack 70 Anthracite duff 30	Box test				—	—	63·6	69·0	—	—
29L (*b*) iv. S. Yorks.	P. and S. slack 60 Anthracite duff 40	Box test				—	—	86·4	90·2	—	—
29M S. Yorks.	Parkgate and Silkstone slack 70·0 Anthracite duff 30·0	Top charge	9·0	24¼	21	20·2	46·2	79·5	91·0	95·6	97·1
29N S. Yorks.		Top charge	9·0	20	21	22·7	43·8	73·6	86·8	94·8	96·7
29O S. Yorks.		Top charge	9·0	9½	14	1·0	15·6	49·9	72·5	91·0	96·6
29B (*b*) S. Yorks.	Parkgate and Silkstone slack, thro' ⅛ in.	Box test		25¼		15·8	38·2	78·5	85·9	92·8	97·1
29P (*b*) I. i. S. Yorks.	2½% P. and S. slack, ground thro' 200 mesh, and ordinary P. and S. slack	Box test		25¼		26·6	47·3	63·4	73·3	82·3	88·7
29P (*b*) I. ii. S. Yorks.	5%	Box test		25¼		20·7	40·5	67·7	81·0	89·3	94·6
29Q (*b*) I. i. S. Yorks.	1% Low temp. breeze, ground thro' 200 mesh, and ordinary P. and S. slack	Box test		26¼		37·6	53·0	74·8	85·2	92·1	97·7
29Q (*b*) I. ii. S. Yorks.	2½%	Box test		26		56·5	65·6	79·4	86·9	94·0	97·2
29Q (*b*) I. iii. S. Yorks.	5%	Box test		24		35·3	59·5	84·8	93·1	95·6	96·5
29Q (*b*) I. 1. S. Yorks.	1% Low temp. breeze (as used above) ground thro' 200 mesh, and blended with ordinary Parkgate and Silkstone coking slack, thro' ⅛ in.	Box test		23¼		43·2	60·7	77·6	85·7	91·5	96·2
29Q (*b*) I. 2. S. Yorks.	2%	Box test		23¼		25·3	41·0	51·0	55·0	63·1	71·8
29Q (*b*) I. 3. S. Yorks.	3%	Box test		23¼		27·4	62·5	79·7	85·0	91·2	96·0
29Q (*b*) I. 4. S. Yorks.	4%	Box test		24½		28·4	53·6	75·8	83·0	89·7	95·2
29Q (*b*) I. 5. S. Yorks.	5%	Box test		24½		25·5	50·8	82·4	89·9	94·1	97·1
29Q (*b*) I. 6. S. Yorks.	6%	Box test		24½		10·1	32·2	61·5	78·3	88·9	94·6
29Q (*b*) II. i. S. Yorks.	2½% L. T. breeze (as above) ground thro' 100 mesh, and ordinary P. and S. slack	Box test		24½		50·1	64·0	76·2	82·8	89·2	94·4
29Q (*b*) II. ii. S. Yorks.	5%	Box test		27¼		37·2	55·8	71·7	79·5	87·9	93·4

Average Shatter Indices (per cent.).				Density and Porosity.				Analysis (per cent. on air-dried basis).				
On 2 in.	On 1½ in.	On 1 in.	On ½ in.	Apparent S.G.	Real S.G. (ash-free).	Apparent Porosity (per cent.).	Total Porosity (per cent.).	Moisture.	Ash.	Volatile Matter (less moisture).	Sulphur.	Coke No.
60·2	72·2	86·8	96·7	0·96	1·71	35·6	46·4	0·4	10·2	0·8	1·7	28D
59·7	72·0	82·4	95·6	0·92	1·70	37·1	48·3	0·6	10·1	1·3	1·5	28E
57·0	69·9	85·5	96·0	0·86	1·76	42·9	53·0	1·3	9·4	1·6	1·8	28F
64·5	79·0	91·0	97·6	1·02	1·81	34·8	45·4	0·5	9·2	1·3	1·5	29A
74·1	86·7	94·1	97·4	0·85	1·80	45·3	54·2	0·6	9·4	1·2	1·4	29B
65·6	85·2	95·2	97·7	0·85	1·83	37·5	55·0	0·2	9·8	0·6	1·5	29C
67·5	80·2	90·8	96·7	0·86	1·74	44·1	52·7	2·0	11·1	2·1	1·4	29D
65·0	80·9	91·1	96·9	0·84	1·76	42·7	54·3	1·6	11·5	1·2	1·4	29E
72·9	85·9	94·8	97·7	0·89	1·88	41·6	54·2	0·3	9·6	0·9	1·4	29F
62·5	82·8	94·3	97·6	0·88	1·85	36·8	54·6	0·4	10·4	1·0	1·6	29G
*59·1	*77·0	90·1	97·6									29H
79·0	86·5	—	—									29I (*b*) i.
79·3	86·9	—	—									29I (*b*) ii.
85·5	88·0	—	—									29I (*b*) iii.
85·3	89·2	—	—									29I (*b*) iv.
83·2	88·0	92·8	95·8	0·89		39·8						29I (*b*) v.
80·4	84·1	87·5	90·1									29I (*b*) vi.
80·2	89·0	95·2	97·3	0·81	1·83	49·7	56·9	2·0	7·8	1·4	1·2	29J
79·4	88·1	93·5	96·4	1·00	1·81	32·3	46·2	0·5	7·7	1·2	1·3	29K
69·2	85·2	92·0	96·1	0·78		47·3						29L (*b*) i.
74·7	88·1	—	—									29L (*b*) ii.
85·2	89·6	—	—									29L (*b*) iii.
72·8	85·9	—	—									29L (*b*) iv.
72·3	90·1	96·4	98·1	1·03	1·78	36·0	43·7	0·7	7·7	1·1	1·2	29M
66·9	84·5	94·7	97·3	0·89	1·76	38·1	51·1	1·4	7·7	2·6	1·1	29N
52·6	73·9	91·1	97·4	1·11	1·76	31·2	39·0	0·7	7·7	1·2	1·2	29O
69·7	86·9	94·1	97·3	0·87		41·3						29B (*b*)
66·7	81·7	91·2	96·0	0·74		37·3						29P (*b*) I. i.
61·7	82·5	93·0	97·2	0·82		42·6						29P (*b*) I. ii.
70·3	87·9	94·7	97·8	0·85		44·6						29Q (*b*) I. i.
81·1	91·1	95·1	97·8	0·81		42·9						29Q (*b*) I. ii.
59·0	82·0	93·7	96·9	0·84		34·4						29Q (*b*) I. iii.
67·1	83·6	94·2	97·6	0·86		43·2						29Q (*b*) I. 1.
76·5	85·0	91·5	95·0	0·78		45·7						29Q (*b*) I. 2.
74·7	88·0	94·8	97·2	0·89		43·3						29Q (*b*) I. 3.
61·8	86·1	95·2	97·5	0·89		42·7						29Q (*b*) I. 4.
74·6	91·3	96·1	97·8	0·88		41·7						29Q (*b*) I. 5.
64·4	84·7	94·5	97·2	0·92		39·8						29Q (*b*) I. 6.
63·8	84·5	93·6	97·4	0·83		38·0						29Q (*b*) II. i.
57·0	76·2	89·9	96·0	0·74		35·7						29Q (*b*) II. ii.

Coke No. and District.	Coke Data.					Average Size Analysis (per cent.).					
	Details of Coals used.	Method of Charging.	Moisture in Coal (per cent.).	Coking Time (hr.).	Oven Width (in.).	On 4 in.	On 3 in.	On 2 in.	On 1½ in.	On 1 in.	On ½ in.
29Q (*b*) III. i. S. Yorks.	2½% L. T. breeze (as above) ground thro' 60 mesh, ordinary P. and S. slack	Box test		24½		52·6	66·5	78·4	84·0	88·2	92·8
29Q (*b*) III. ii. S. Yorks.	5%	Box test		27¼		50·5	66·5	83·1	88·5	94·2	97·2
29Q (*b*) III. iii. S. Yorks.	10%	Box test		27¼		24·8	39·3	53·3	62·9	75·7	91·5
29R (*b*) I. i. S. Yorks.	2% Low temp. breeze, thro' 200 mesh, and ordinary P. and S. coking slack	Box test		24½		39·6	62·2	82·1	88·6	93·6	96·9
29R (*b*) I. ii. S. Yorks.	3%	Box test		24½		33·7	48·3	60·9	67·2	73·8	81·2
29S (*b*) i. S. Yorks.	2½% Barnsley dust (D.M.) blended with ordinary Parkgate and Silkstone coking slack, ground thro' ⅛ in.	Box test		24½		31·4	48·3	63·0	68·2	75·9	82·1
29S (*b*) ii. S. Yorks.	5%	Box test		26¼		56·9	68·8	81·0	85·7	92·5	97·5
29S (*b*) iii. S. Yorks.	10%	Box test		26		52·3	68·1	80·2	86·1	93·9	97·4
29S (*b*) iv. S. Yorks.	15%	Box test		26¼		71·4	79·5	85·5	92·0	96·0	98·3
29S (*b*) v. S. Yorks.	20%	Box test		26		52·0	75·7	90·1	93·9	96·0	98·0
29T (*b*) I. i. S. Yorks.	2½% H. T. coke, thro' 200 mesh, and P. and S.	Box test		24		59·6	73·0	87·2	93·2	96·0	98·2
29U (*b*) I. i. S. Yorks.	2½% L. T. breeze (Barnsley coal) ground thro' 200 mesh	Box test		22½		28·8	61·2	83·7	91·9	95·6	97·8
29V (*b*) I. i. S. Yorks.	2½% Low volatile coal thro' 200 mesh and P. and S. slack	Box test		22½		14·6	43·6	69·1	81·5	90·0	95·4
29W (*b*) I. i. S. Yorks.	1% Low temperature breeze ground thro' 200 mesh and blended with ordinary Parkgate and Silkstone coking slack, thro' ⅛ in.	Box test		26¾		53·8	67·0	78·1	83·1	88·0	91·6
29W (*b*) I. ii. S. Yorks.	2%	Box test		26¾		63·7	73·9	87·9	93·7	96·5	98·4
29W (*b*) I. iii. S. Yorks.	3%	Box test		26¾		70·2	85·7	90·4	93·6	96·5	98·3
29W (*b*) I. iv. S. Yorks.	4%	Box test		22½		23·8	42·8	76·2	88·6	93·9	97·2
29W (*b*) I. v. S. Yorks.	5%	Box test		22½		34·0	53·8	72·1	79·5	85·6	90·4
29W (*b*) I. vi. S. Yorks.	6%	Box test		24¾		20·0	43·7	75·6	87·4	93·2	96·4
29W (*b*) I. vii. S. Yorks.	7%	Box test		24¾		12·5	33·0	71·1	85·2	92·5	96·0
29W (*b*) III. ii. S. Yorks.	2% Low temp. breeze ground thro' 60 mesh and blended with ordinary P. and S. coking slack	Box test		23¾		56·0	66·0	75·8	81·8	89·5	94·5
29W (*b*) III. iii. S. Yorks.	3%	Box test		23¾		47·3	62·2	76·4	81·7	84·8	87·4
29W (*b*) III. iv. S. Yorks.	4%	Box test		24		10·9	33·1	60·1	74·1	85·7	93·0
29W (*b*) III. v. S. Yorks.	5%	Box test		24		20·6	56·4	82·5	92·4	96·8	98·2
30A Durham	Busty 100	Top charge	2·0	26½	20¾	46·2	76·8	92·0	96·0	97·5	98·4
30B Durham	Victoria 100	Top charge	4·4	36	20¾	58·1	82·1	94·1	96·8	97·9	98·6
30B (*b*) Durham	Ditto (in exptl. oven)		4·4	23	20¾	34·0	65·9	94·3	96·6	97·8	98·3
30C (*b*) s. Durham	Slurry (in exptl. oven)		11·5	20¼	20¾	6·1	52·4	85·8	94·7	96·8	97·8
31A S. Yorks.	Halifax Soft (T.) 100	Top charge		72	Bee-hive	44·0	80·7	95·9	97·7	98·8	99·1
31B S. Yorks.	Halifax Soft (T.) 100	Top charge		72	Bee-hive	12·6	35·4	74·6	87·0	94·8	96·9
32 S. Yorks.	Haigh Moor Barnsley	Cake charge	15·0	35	20	27·9	52·1	75·5	86·0	93·5	—
33 S. Yorks.	Barnsley 100	Cake charge	10·0	39	20	9·1	26·3	59·4	77·0	89·3	—
34 S. Yorks.	Parkgate 40 Fenton 40 Beamshaw 20	Top charge	12·0	32	20	27·5	49·2	69·6	82·7	92·5	—
35 S. Yorks.	Fenton Silkstone Parkgate	Cake charge	12·7	36	20¾	19·9	44·2	68·9	83·2	93·3	—
36A Sarre	Sarre coal	Cake charge		27	18	24·4	42·6	61·8	73·1	86·8	97·1
36B Sarre	Sarre coal 83 Low temp. breeze 17	Cake charge		23½	18	22·3	52·0	84·9	93·8	96·8	98·2
37 S. Yorks.	Barnsley 100	Cake charge	9·0	36	21½	10·0	27·6	64·5	80·3	92·4	97·9

Average Shatter Indices (per cent.).				Density and Porosity.				Analysis (per cent. on air-dried basis).				Coke No.
On 2 in.	On 1½ in.	On 1 in.	On ½ in.	Apparent S G.	Real S.G. (ash-free).	Apparent Porosity (per cent.).	Total Porosity (per cent.)	Moisture.	Ash.	Volatile Matter (less moisture).	Sulphur.	
54·9	76·2	91·4	96·3	0·85		36·7						29Q (*b*) III. i.
66·3	82·1	93·9	97·4	0·88		37·8						29Q (*b*) III. ii.
66·0	78·8	87·5	94·0	0·89		37·2						29Q (*b*) III. iii.
71·2	84·4	93·9	97·4	0·85		42·5						29R (*b*) I. i.
77·0	84·6	90·9	94·7	0·70		38·3						29R (*b*) I. ii.
65·3	79·8	90·8	96·0	0·80		37·1						29S (*b*) i.
73·6	90·3	96·0	98·1	0·87		45·5						29S (*b*) ii.
80·9	90·6	96·1	97·8	0·78		48·4						29S (*b*) iii.
78·7	89·6	96·6	98·2	0·90		45·9						29S (*b*) iv.
72·1	89·3	95·1	97·7	0·92		40·8						29S (*b*) v.
65·1	83·2	93·9	97·6	0·84		46·3						29T (*b*) I. i.
63·7	83·8	95·0	98·1	0·90		44·6						29U (*b*) I. i.
47·2	76·1	90·8	96·7	0·81		47·3						29V (*b*) I. i.
72·2	85·3	93·6	96·7	0·84		33·6						29W (*b*) I. i.
68·3	85·0	95·0	97·9	0·88		41·6						29W (*b*) I. ii.
74·0	87·0	95·5	97·9	0·93		36·4						29W (*b*) I. iii.
56·5	79·6	93·2	97·4									29W (*b*) I. iv.
62·8	79·5	92·0	96·5	0·87		36·8						29W (*b*) I. v.
61·0	86·1	95·8	98·2	0·92		43·3						29W (*b*) I. vi.
64·3	84·3	95·5	98·0	0·79		38·3						29W (*b*) I. vii.
64·2	79·6	91·9	96·0	0·82		39·9						29W (*b*) III. ii.
75·6	86·3	94·2	97·3	0·82		38·6						29W (*b*) III. iii.
65·9	86·0	94·0	97·3	0·81		46·5						29W (*b*) III. iv.
64·6	85·8	95·1	98·4	1·02		43·6						29W (*b*) III. v.
84·5	92·7	96·7	98·1	0·95	1·80	40·0	49·3	1·0	11·1	2·3	0·9	30A
87·8	95·2	97·7	98·6	0·88	1·96	43·1	55·9	0·1	5·4	0·9	0·7	30B
80·0	93·7	97·2	98·3	0·79		42·4						30B (*b*)
74·8	90·0	96·0	97·5	0·90		40·5						30C (*b*) s.
81·0	91·7	96·6	98·4	0·92	1·94	41·9	53·8	0·3	8·0	1·4	0·8	31A
3·3	86·7	94·2	96·8	0·82	1·85	52·3	56·5	0·7	5·4	1·4	0·7	31B
*67·7	*78·1	89·9	97·2					3·5	8·4	3·6	1·0	32
*71·1	*81·8	92·5	97·9					0·9	7·2	2·2	0·9	33
*71·5	*81·7	92·2	97·5					0·2	8·0	1·4	1·5	34
*60·2	*74·1	88·9	97·4					1·3	10·5	2·9	1·4	35
*64·8	*75·0	86·0	97·3	0·90	1·74	39·8	50·6	1·5	10·3	2·6	0·6	36A
80·0	92·7	97·3	98·7	0·93	1·79	41·7	50·3	1·5	11·3	3·1	0·8	36B
43·7	61·9	83·5	97·4	0·90	1·71	35·1	48·6	2·2	5·3	2·8	1·0	37

Coke No. and District.	Coke Data.					Average Size Analysis (per cent.).					
	Details of Coals used.	Method of Charging.	Moisture in Coal (per cent.).	Coking Time (hr.).	Oven Width (in.).	On 4 in.	On 3 in.	On 2 in.	On 1½ in.	On 1 in.	On ½ in.
38A S. Yorks.	Silkstone 50 Beeston 50	Top charge	13·2	25½	19¾	15·2	30·7	58·1	69·9	83·9	95·8
38A s. S. Yorks.	Ditto Washed slurry	Top charge	27·0	30	19¾	36·3	76·3	90·4	95·5	96·3	97·6
38A r. S. Yorks.	Ordinary slack, with slurry	Top charge	13·0	25	19¾	37·3	61·1	80·1	85·7	91·4	96·9
38A (*b*) s. S. Yorks.	Slurry	Box test				34·5	63·4	81·8	85·3	88·9	95·5
38B (*b*) i. S. Yorks.	Ordinary slack, without slurry	Box test				29·7	62·1	82·8	88·8	93·0	96·3
38B (*b*) iii. S. Yorks.	8% Dust (25% fusain) blended with ordinary slack (without slurry). (Dust weathered)	Box test				34·1	54·5	81·8	90·5	95·6	97·8
38B (*b*) iv. S. Yorks.	12%	Box test				32·2	57·4	81·9	89·9	94·3	97·5
38B (*b*) v. S. Yorks.	16%	Box test				19·7	48·7	77·8	88·4	94·6	97·7
38C i. S. Yorks.	Silkstone and Beeston 91 Low temp. breeze 9	Top charge	10·0	21–22	19¾	48·9	59·5	67·4	71·3	77·9	90·2
38C ii. S. Yorks.	S. and B. 88 Low temp. breeze 12	Top charge	9·9	21–22	19¾	89·7	90·6	90·7	90·8	91·7	94·2
38C iii. S. Yorks.	S. and B. 82 Low temp. breeze 18	Top charge	9·5	21–22	19¾	78·8	81·2	82·3	83·7	86·0	90·7
38C iv. S. Yorks.	S. and B. 78 Low temp. breeze 22	Top charge	9·0	21–22	19¾	81·9	84·7	86·9	87·7	89·6	92·4
39 S. Wales	Two Foot Nine 100	Top charge	8·0	48	17½	64·6	86·5	95·6	97·9	98·5	98·9
40A Lancs.	Lower Mountain Mine (H.)	Top charge		96	Beehive	86·6	91·8	95·7	97·7	98·8	99·3
40B Lancs.	Lower Mountain Mine (C.)	Top charge		96	Beehive	87·6	93·6	97·3	98·7	99·3	99·5
41 Durham	Brockwell Hutton Busty	Top charge	2·5	26	21	56·1	94·7	98·2	98·8	99·2	99·4
42A Derby.	Black Shale 100	Top charge	12·0	72	Beehive	21·9	33·9	49·5	60·0	73·6	93·8
42B Derby.	Black Shale 50 Silkstone 50	Top charge	12·0	72	Beehive	48·2	65·1	80·9	90·2	96·2	98·3
43 S. Wales	Mixture of eight seams	Top charge	8·5	26	19	51·0	82·6	95·5	97·6	98·5	99·0
44 S. Yorks.	Parkgate 80 Fenton 20	Top charge	10·0	33	19¾	52·0	67·9	81·8	87·8	94·1	97·0
45A Derby.	Tupton 60, Main 19, Deep Soft 14, Kilburn 7	Cake charge	13·5	27	19¾	3·8	21·3	63·3	80·7	92·3	97·4
45B Derby.		Cake charge	13·5	36	20	10·7	33·7	69·2	82·4	91·7	96·0
46A S. Yorks.	Mixture of eight S. Yorks. slacks	Top charge	8·2	14	14	9·3	54·2	91·4	95·1	97·3	98·4
46B S. Yorks.	Mixture of ten S. Yorks. slacks	Top charge	8·2	—	16	17·5	54·5	83·2	93·5	97·3	98·6
46C S. Yorks.		Top charge	9·5	21½	18	20·7	54·3	90·5	95·7	97·8	98·4
46D S. Yorks.		Cake charge	10·0	30	18	43·4	69·0	85·9	91·8	96·0	98·3
46E S. Yorks.	Mixture of seven S. Yorks. slacks	Top charge	7·4	22½	20	23·9	53·9	81·9	89·4	94·7	97·3
46F S. Yorks.		Top charge	8·0	30	20½	6·4	33·3	70·8	84·0	92·2	95·7
46G (*b*) S. Yorks.		Box test				33·2	59·0	80·7	87·4	93·4	96·2
47 Lancs.	Mountain Mine Upper and Lower (A.) 100	Top charge	10·0	22	19	43·0	74·6	89·5	92·7	95·5	97·2
48 Lancs.	Mountain Mine (U.) 90 Other slacks 10	Cake charge	10·0	35	20	50·2	80·8	91·7	95·7	97·5	98·5
49 S. Yorks.	Halifax Soft (F.) 100	Top charge	4·0	26	19¾	55·2	91·0	97·3	98·2	98·8	99·2
50A (*b*) S. Wales	L. steam coal	Box test				55·7	79·2	95·3	98·1	98·5	98·9
50B (*b*) S. Wales	No. 3 house coal (bituminous)	Box test				54·5	81·6	96·9	99·0	99·4	99·7
50C (*b*) S. Wales	B. coal	Box test				61·5	81·0	96·0	98·6	99·2	99·6
51A Leicester.	92% low temp. coke 8% pitch	Coke breeze from non-coking coal briquetted with pitch, carbonised in vertical gas retorts at 900° C.				Ovoid briquettes, 1½ in. size.					
51B Leicester.	88% low temp. coke 12% pitch					Ovoid briquettes, 1½ in. size.					
52	Electrode graphite					—	—	—	—	—	—
53	Wood charcoal (from mixture of English hardwoods)					—	—	—	—	—	—
54A	Pitch coke, made in beehive ovens										
54B S. Yorks.	Pitch coke, made in boxes from tar still residues					0·0	1·2	23·6	51·6	78·3	90·1
55 Ceylon	Natural graphite					—	—	—	—	—	—

Average Shatter Indices (per cent.).				Density and Porosity.				Analysis (per cent. on air-dried basis).				Coke No.
On 2 in.	On 1½ in.	On 1 in.	On ½ in.	Apparent S.G.	Real S.G. (ash-free).	Apparent Porosity (per cent.).	Total Porosity (per cent.).	Moisture.	Ash.	Volatile Matter (less moisture).	Sulphur.	
*55·2	*71·6	85·5	96·5	0·76	1·78	40·5	59·0	1·3	9·9	2·4	1·0	38A
78·2	88·6	95·4	98·1	0·81	1·72	43·4	55·9	2·5	15·6	3·1	1·1	38A s.
59·7	67·5	80·3	94·4	0·80	1·71	43·6	55·0	1·7	9·6	3·0	1·2	38A r.
76·1	88·0	94·9	98·0	0·81	1·81	50·4	57·7	1·2	14·2	2·6	1·2	38A (*b*) s.
59·5	78·6	90·9	97·5	0·86	1·86	48·0	55·0	1·1	8·3	1·6	0·9	38B (*b*) i.
55·7	78·3	91·2	97·7	0·89		45·7						38B (*b*) iii.
60·5	76·1	89·6	97·3	0·90	1·74	41·7	50·3	1·1	9·0	2·3	0·9	38B (*b*) iv.
54·8	76·1	90·6	97·7	0·95		41·4						38B (*b*) v.
*67·6	*73·9	80·5	91·7	0·91		40·8						38C i.
*68·3	*70·7	76·1	86·8	0·85		42·0						38C ii.
*81·4	*83·4	86·3	91·9	0·86		41·3						38C iii.
*79·0	*82·6	85·4	90·9	0·88		43·6						38C iv.
89·8	96·9	98·5	99·0	0·83	1·93	45·6	57·5	0·3	4·2	0·8	0·6	39
77·1	88·8	96·1	98·2	1·03	1·80	28·2	44·6	1·2	8·9	2·1	0·5	40A
80·4	89·3	96·0	98·3	1·05	1·78	28·2	42·9	0·6	7·9	1·7	0·6	40B
*85·8	*92·9	97·2	98·7	0·92	1·86	39·8	51·6	0·3	7·0	1·1	0·8	41
60·5	71·3	83·6	93·6	0·84	1·78	41·2	54·3	1·6	7·9	1·2	0·9	42A
67·2	77·4	89·1	95·5	0·80	1·66	40·5	55·8	1·7	19·0	1·1	2·3	42B
90·7	96·3	98·3	98·9	0·93	1·88	35·5	52·0	0·5	8·2	1·1	1·1	43
67·5	77·7	89·7	96·8	1·01	1·86	33·7	47·4	0·4	9·9	1·1	1·3	44
*47·0	*67·9	85·7	97·1	0·86	1·74	35·0	52·0	0·3	7·2	1·8	1·4	45A
53·8	70·4	86·3	96·5	0·90	1·73	34·2	49·8	1·6	8·1	2·3	1·7	45B
76·5	87·4	94·0	97·3	0·91	1·78	40·2	51·0	0·8	11·2	2·2	1·1	46A
74·2	84·7	93·1	97·0	0·95	1·82	38·9	49·5	1·3	9·6	2·9	1·3	46B
*81·5	*89·8	96·4	98·2	0·98	1·79	37·2	47·8	0·4	13·1	1·3	1·3	46C
*66·4	*78·1	89·4	96·4	1·00	1·75	29·9	45·7	1·3	11·8	2·6	1·3	46D
64·7	79·2	90·4	96·8	0·96	1·81	38·3	49·0	0·6	10·1	2·7	1·4	46E
71·6	84·9	93·4	97·4	0·94	1·78	43·2	49·5	0·4	10·9	1·5	1·4	46F
70·5	82·9	92·2	96·9	0·92	1·78	41·3	50·2	1·8	9·8	2·3	1·4	46G (*b*)
87·5	92·2	95·9	97·9	1·01	1·87	39·4	48·3	0·3	12·6	1·4	1·0	47
84·0	90·9	95·9	98·2	0·91	1·74	23·6	50·5	1·7	13·3	2·1	1·4	48
86·5	92·3	96·2	97·9	1·01	1·91	42·9	49·5	0·2	12·6	1·1	0·7	49
85·9	97·2	98·0	98·4	0·93	1·95	45·6	52·9	0·1	3·4	0·7	0·7	50A (*b*)
83·8	94·3	97·5	98·5	0·95	1·91	42·0	51·2	0·1	7·5	0·9	1·2	50B (*b*)
76·0	90·2	96·7	98·6	1·08	1·81	31·0	41·4	0·2	4·4	1·1	0·7	50C (*b*)
—	87·4	95·1	96·1									51A
—	95·5	97·1	97·5	0·83	1·67	47·7	53·2	5·1	13·6	4·9	1·2	51B
—	90·2	98·3	98·8	1·54	2·15	16·0	28·4	0·1	0·8	0·8	0·03	52
—	—	—	—	0·55	1·40	39·1	61·9	4·9	4·0	23·5	0·2	53
57·9	80·5	90·5	95·0	0·96	1·78	40·0	46·4	1·8	1·7	2·2	0·7	54A
								0·3	15·6	2·7	5·1	54B
—	—	—	—	1·90	2·23	14·5	15·2	0·2	4·7	1·4	0·1	55

NAME INDEX

A

Agde and Schmitt, 120
Allen and Palmer, 62
American Society for Testing Materials, 67, 73, 76, 77, 82, 94, 95, 98, 106
Anderson, 65, 67, 69
Arend and Wagner, 121
Audibert, 4, 42
Audibert and Delmas, 171
Augustine. *See* Kreisinger.

B

Bailey and Evans, 19, 144
Barash, 168, 169
Beebee, 225
Beet, 60
Belden, 94
Bell, 15, 17, 65, 73, 74, 117, 213
Bestehorn. *See* Haüsser.
Blizard. *See* Sherman.
Bolling, 141
Bönnemann, 184
Boudouard, 121
Bradley and Mott, 21, 175
Brassert, 118
Braunholtz, Briscoe and Nave, 68, 199
Briscoe. *See* Braunholtz.
Burdekin, 168, 169
Bury, 213
Byrom and Christopher, 204

C

Campredon, 168
Carton, 81
Chatelier, Le, 43
Christopher. *See* Byrom.
Clements, 19, 119, 144
Cobb. *See* Greenwood.
Cochrane, 15, 73, 74, 75, 85
Cooper, 213
Croxton, 94
Curran, 78, 79

D

Deladrière, 144
Delmas. *See* Audibert.
Derclaye, 145, 146
Donath, 159
Dorflinger, 80, 81
Drakeley, 157

E

Erdmann, 159
Eschka, 61
Evans, 19, 199
Evans. *See* Bailey.
Evans. *See* Sutcliffe.

F

Finn, 108
Foxwell, 4, 35, 36, 39, 171
Fuel Research Board, 5, 6, 61, 62, 168
Fulton, 64

G

Gill, 146
Gould. *See* Powell.
Greenfield and Harrison, 199
Greenwood, 69

H

Hadfield, 16
Harrison. *See* Greenfield.
Haüsser and Bestehorn, 122, 123, 124, 219, 221
Haven, 73, 75, 76, 78, 85
Hebden, 225
Hewson, 15, 74
Hickling, 157, 158, 160, 163
Hiles and Mott, 60
Hilgenstock, 213
Hollings, 118
Howland, 17, 118, 119, 120

I

Illingworth, 81

J

Johnson, 118, 136, 144
Jones, 73
Joseph. *See* Royster.

K

Kinney. *See* Perrott.
Koppers, 17, 120, 125, 141
Korevaar, 136
Kreisinger, Ovitz and Augustine, 125, 138

L

Lilot, 144
Louis, 146

M

Malleis, 65, 66
Marquard, 78
ter Meulen, 61
Meurice, 168, 169
Midland Coke Research Committee, v, vii, 6, 8, 52, 57, 61, 95, 108, 110, 116, 125, 126, 213, 232, 233

Morfey, 231
Mott, 21, 60, 210
Mott. *See* Bradley.
Mott. *See* Hiles.

N

Nave. *See* Braunholtz.
Northern Coke Research Committee, vii, 8, 68, 70, 81, 95, 116, 208, 230

O

Ovitz. *See* Kreisinger.

P

Palmer. *See* Allen.
Perrott and Kinney, 15, 16, 73, 75, 78, 94
Perrott and Sherman, 120
Pollard. *See* Strahan.
Porter, 213
Powell and Gould, 76, 78
Purves, 110, 222

R

Ralston, 157
Ramsberg and Sperr, 65, 66
Rice, 15, 16, 73, 75, 85
Rose, 14, 45, 53, 66, 67
Royster and Joseph, 138

S

Safety in Mines Research Board, 5, 6
Schmitt. *See* Agde.
Schmolke, 15, 86, 91
Scott, 62
Scott, G. S., 144
Scottish Coke Research Committee, vii, 8, 95, 116
Seyler, 154, 156, 157
Sherman, 125
Sherman and Blizard, 125, 132
Sherman and Perrott, 120
Simmersbach, 73, 79, 80, 141, 213
Slater, 38, 168, 169, 171
Sperr. *See* Ramsberg.
Strahan and Pollard, 158
Sutcliffe and Evans, 67

T

Taylor, McKenzie, 159, 160
Thiessen, 156
Thörner, 65, 117

U

U.S. Bureau of Mines, 16, 75, 94, 120, 125, 126, 131, 156, 157

W

Wagner. *See* Arend.
White, 156
Wüst, 120

SUBJECT INDEX

A

Abradability of coke, 11, 15, 73 *seq.*, 101, 107
  effect of method of oven charging on, 205, 206
Abrasion index, 88, 90, 91
Abrasion in blast furnace, 118
Abrasion test, drum, 31, 55, 57, 73 *seq.*
  true, 86, 87, 88, 91, 92, 93
Agglutinating power of coal, 154, 168
American tumbler tests, 75, 76, 77, 78, 79
Analysis, of coke, 55 *seq.*
  pulverising of coke for, 58
  sampling of coke for, 57
  ultimate, of coals, 165
Anthracitic coals, 153, 156, 157, 160
Anthracite duff blends, 183, 184
  friability of, 184
Apparent density of coke, 11, 14, 64, 65, 66, 67, 68, 71
Appearance of coke, 43
Arsenic, determination of, 62
Ash, determination of, 55, 60
Ash content of coke and method of pulverising, 58
Ash in coke, its effect on blast-furnace working, 142, 143, 144, 145, 146, 147
Attrition in blast furnace, 30, 31, 32, 88, 91

B

Bag tests, 231
  comparison of, with full-scale oven tests, 231
Belgian fat coals, 179
  lean coals, 179
Binding agent, 2, 3
Bituminous coal, 153, 156, 157, 159, 160, 161, 162, 163, 166
  banded, 163
  chemistry of, 161 *seq.*
  formation of, 159
  soluble constituents in, 161
Blast furnace, abrasion in, 16, 118
  attrition in, 15, 20, 30, 31, 32, 88, 91
  consumption of coke in, 17, 142 *seq.*
    and ash content, 142 *seq.*
    and moisture content, 142 *seq.*
  direct reduction in, 118, 119
  practice, and reactivity of coke, 139, 140
  sampling at, 112, 113
  significance of coke reactivity in, 17, 117
Blast furnace, slag formation in, 143
  solution loss in, 17, 18, 117, 118
  stresses in, 11, 16
  trials, 120, 234, 235
  useful size of coke in, 18, 19, 20
Blending, and rate of heating, 43
  and size of coke, 22, 40
  and quality of coke, 179 *seq.*
  British practice in, 179
  Continental practice in, 179
  of coking coal and fusain, 186 *seq.*
  of coking coal and low-temperature coke, 22, 184, 185, 186
  of coking and low-volatile non-caking coals, 183 *seq.*
  of coking and non-coking coals, 42, 179, 180
  of coking coal with dust rich in fusain, 189, 190
  of two coking coals, 181
  value of fusain in, 190, 191
  with anthracite duff, 22, 183, 184
  with finely-ground low-temperature breeze, 40, 188, 189
  with fusain diluted with coal dust, 192, 193
  with fusain substitutes, 193
  with high-temperature coke breeze, 193
  with low-volatile non-caking coals, 180
  with " pure " fusain, 191, 192
  with slurry, 190, 191
Blocky coke, 12, 23, 24, 97, 104, 105, 116
Box tests, 228 *seq.*
  comparison of, with full-scale oven tests, 230
Breeze formation, 21, 27, 28, 30, 33, 94, 222, 226, 227
British tumbler tests, 74
Brown coals, 156, 159, 162
Bulk density of coke, 11, 15, 70
  effect of, on abrasion, 88

C

Cake-charging, 24, 52, 204, 208, 209
Caking coal, 154
Caking indices, 168, 169
  and shatter indices, 168, 169
Caking power of coal, 154, 164, 168 *seq.*
  and coking power, 168
  determination of, 168, 169
Calorific value of coal, 154
Carbon content of coals, 165, 166, 169
  and coke quality, 166
Carbon, determination of, 62
Carbon dioxide, reactivity of coke with, 11, 17, 133, 134, 135

Cell structure of coke, 64, 65
Cell walls, 14
Cellulose in coal, 161
Central quenching, 224, 225
Chemical analysis of coke, 11, 15
Chemical properties of coke and its specification, 142 *seq.*
Chemistry of bituminous coal, 161 *seq.*
Classification of coal, 154, 161, 163, 164
Clarain, 163
Closed pores, 14
Coal, agglutinating power of, 154, 168
  anthracitic, 2, 153, 156, 157
  banded bituminous, 163
  Belgian, fat, 178, 179
    lean, 178, 179
  binding agent in, 2, 3
  bituminous, 153, 156, 157, 159, 160, 161, 166
    chemistry of, 161 *seq.*
    formation of, 159, 160
    soluble constituents in, 161, 162
  blending of, and quality of coke, 179 *seq.*
    and size of coke, 22, 40
    British practice in, 179
    Continental practice in, 179
    with anthracite duff, 183, 184
    with dust rich in fusain, 189, 190
    with fusain, 186 *seq.*
    with fusain diluted with coal dust, 192, 193
    with fusain substitutes, 193
    with high-temperature coke breeze, 193
    with low-temperature coke breeze, 40, 184, 185, 186, 188, 189
    with low-volatile non-caking coal, 180, 183 *seq.*
    with non-coking coal, 42, 179, 180
    with "pure" fusain, 191, 192
    with slurry, 190, 191
  brown, 156, 159, 162
  cake charging of, 52
  caking, 154
  caking indices of, 169
    and shatter indices of cokes, 168, 169
  caking power of, 6, 154, 164, 168 *seq.*
    and coking power, 6, 168, 169
    determination of, 168, 169
  calorific value of, 154
  carbon content of, 165, 169
    and coke quality, 166
  cellulose in, 161
  character of, its influence on the coke, 153 *seq.*
  classification of, 154, 163, 164
  clarain in, 163
  coarse crushing of, 197, 202
  coking, 153, 154, 166
    carbon contents of, 166
    Derbyshire, 164, 165, 166
    Durham, 164, 165, 166
    good, 167
    moisture contents of, 166
    oxygen contents of, 166
    poor, 167
    shale in, 2, 199, 200
Coal, coking, shale in, as points of weakness, 2, 200, 201
    South Wales, 164, 165, 166
    volatile matter contents of, 166
    Westphalian, 179
    Yorkshire, 164, 165, 166
  coking power of, 2, 3, 175
    and caking power, 168, 169
  coking quality of, its effect on size of coke, 20
  coking value of, and swelling power, 171
  comparison of coarse and fine crushing of, 198
    of graded and through sizes of, 197
  composition of, and tar yields, 164
  constitution of, 154
  contraction of, on heating, 172, 173, 174
  critical maximum size of, for coking, 199
  cuticles in, 2, 156, 161, 162
  Derbyshire, 164, 165, 166
  Durham, 164, 165, 166
  durain in, 163
  expansion of, on heating, 172 *seq.*
  final expansion of, 175
  final plasticity of, 171
  fine grinding of, 22, 197, 202
  formation of, 158 *seq.*
    peat-to-anthracite theory of, 156, 157, 158
      analytical evidence for, 157
      chemical evidence for, 157
      microscopical evidence for, 156
  French, fat, 179
    lean, 179
  fusain in, 163
  gas, Westphalian, 179
  good coking, 167
  graded sizes of, 195, 196
    effect of, on density of coke produced, 201
    effect of, on porosity of coke produced, 201
    effect of, on size of coke produced, 196
    effect of, on strength of coke produced, 196
  initial contraction of, 173, 175
  initial expansion of, 173, 175
  initial plasticity of, 4, 171
  laboratory coking test for, 175 *seq.*
  lignin in, 161
  lignitous, 156, 159, 160
  low volatile, 42, 180
  moisture content of, 166
    its effect on quality of coke produced, 2
  moisture in, as charged to oven, 210 *seq.*
    and smoke abatement, 210
    its effect on coking time, 210, 212
    its effect on quality of coke produced, 210
  non-caking, 154
  non-coking, 154, 167, 175
  oxygen content of, 166
    its effect on coking properties, 2

Coal, percentage expansion of, 175
    its effect on quality of coke produced, 178
  plastic range for, 4, 213
  poor caking, 37
  poor coking, 167
  proximate analysis of, 2, 5
  rational analysis of, 2, 5, 166
  reactivity of, 163, 164
  resins in, 2, 156, 161, 162, 163, 167
  resistant plant tissues in, 2, 156, 161, 162, 163, 167
  size analyses of, as charged in practice, 199, 200
  size of, 21
    its influence on density of coke produced, 201
    its influence on porosity of coke produced, 201
    its influence on quality of coke produced, 195 *seq.*
    its influence on reactivity of coke produced, 202
    its influence on size of coke produced, 21, 195 *seq.*
  softening temperatures of, 4, 171
  South Wales, 2, 164, 165, 166
  spore exines in, 2, 156, 161, 162
  steam, 2, 153. 166
  swelling power of, 171
    its influence on coking value, 171
  temperature of initial contraction of, 173, 175
  temperature of initial expansion of, 173, 175
  temperature of final expansion of, 175
  thermal treatment of, 2, 3, 4, 6, 7
  through sizes of, 195 *seq.*
    effect of, on size of coke produced, 197
    effect of, on strength of coke produced, 197
  ulmin compounds in, 2, 3, 161, 162, 163, 167
    reactivity of, 167
  ultimate analysis of, 2, 5, 164, 165
    in different districts, 165
  value of fine grinding of, 201
  vitrain in, 163
  volatile matter content of, 2, 154, 165, 166
  waxes in, 161, 162, 163, 167
  Westphalian, coking, 179
    gas, 179
    non-coking, 179
  Yorkshire, 164, 165, 166
Coal-forming materials, 160 *seq.*
Coalification process, 157, 158, 159
Coarse crushing of coal, 197, 202
  compared with fine crushing, 198
Coke, abradability of, 11, 15, 31, 73 *seq.*, 101, 107
    development of a test for, 82 *seq.*
    effect on, of bulk density of coke, 88, 89
    effect on, of duration of test, 86
Coke, abradability of, effect on, of free space in drum, 82, 83, 84
    effect on, of method of oven-charging, 205, 206
    effect on, of size of coke tested, 85, 86
    effect on, of using constant volume of coke, 89, 90, 91
    its influence on attrition in blast furnace, 15, 88
  abrasion index for, 88, 90, 91
  apparent density of, 11, 14, 15, 64 *seq.*
    effect on, of size of coal charged, 201
  appearance of, 43
  arsenic in, determination of, 15, 62
  ash content of, and method of pulverising, 58
  ash in, determination of, 55, 60
  average temperature of combustion of, 136, 137
  bag tests for, 231
    compared with full-scale oven tests, 231
  blast-furnace trials on, 234, 235
  blocky, 12, 21, 23, 97, 104, 105, 116
  box tests for, 228, 229, 230
    compared with full-scale oven tests, 230
  breeze formation from, 27, 28, 30, 33, 94, 222, 226, 227
  bulk density of, 11, 15, 70
  carbon in, determination of, 62
  cell structure of, 4, 14, 64, 65
  cell walls in, 14, 33
  chemical analysis of, 11, 15, 55 *seq.*
  combustibility of, 11, 14, 17, 52, 120
    effect on, of porosity of coke, 72
    effect on, of rate of combustion of coke, 125
    effect on, of size of coke, 123
  combustibility test for, 57
  combustion of different sizes of, with standard rate of air supply, 138 *seq.*
  combustion of standard size of, with different rates of air supply, 137 *seq.*
    with standard rate of air supply, 132 *seq.*
  combustion temperature of, 218, 219, 220
  consumption of, in blast furnace, 142
    effect on, of ash content of coke, 143 *seq.*
    effect on, of moisture content of coke, 143 *seq.*
  crushing strength of, 11
  Cumberland, 103, 114, 115
  density of, 64 *seq.*
    effect on, of graded sizes of coal, 201
      of method of oven-charging, 206
      of rate of oven heating, 218, 219
  Derbyshire, 12, 44, 103, 114, 115
  drum test for, 73
  Durham, 12, 13, 43, 44, 103, 114, 115
  effect on, of finely-ground low-temperature breeze, 188, 189
  experimental oven tests for, 231, 232, 234

Coke, fingery, 12, 22, 97, 104, 105, 116
  formation of fractures in, 173
    stages in, 2, 171
  foundry, 37
  fractures in, 13, 14, 33, 34, 35, 44, 46, 47, 52
    longitudinal, 13
    transverse, 13
  from dry dust, 190, 191
  from crushed large coal, 186, 187
  from crushed slack, 186, 187
  from slurry, 186, 187, 190, 191
  hardness of, 11, 14, 16, 23, 47, 73, 74, 94 *seq.*, 107
    effect on, of blending, 23
      of graded sizes of coal, 196
      of method of oven charging, 205, 206
      of porosity of coke, 72
      of rate of heating oven, 216, 217
  hardness number for, 16, 47, 74 *seq.*, 82, 100, 101, 102
    usefulness of, 116
  improvement of quality of, 42
  influence of character of coal on, 153 *seq.*
  Lancashire, 103, 114, 115
  low-temperature, 23, 42, 81
  maximum temperature of combustion of, 135, 136
    effect on, of density, 136
      of total porosity, 136
  mechanical strength index of, 167
  meiler, 117, 140
  methods of research on, 228 *seq.*
  micro-pores in, 14
  micro-structure of, 52
  Micum test for, 73, 80, 81, 141
  moisture in, determination of, 55, 56, 57, 60
  nitrogen in, determination of, 15, 61
  phosphorus in, determination of, 15, 61
  pores in, 14, 33
  pore structure of, 14, 52
  porosity of, 11, 15, 64, 66, 67, 69, 70, 71
    effect on, of graded sizes of coal, 201
      of method of oven-charging, 206
      of size of coal charged, 201
      of rate of heating oven, 218, 219
  prismatic, 12, 104, 105, 116
  production of, 1, 4, 7
  pulverising of, for analysis, 58
  purity of, 11
  quality of,
    and carbon content of coal used, 166
    and percentage expansion of coal used, 178
    and rational analysis of coal used, 178
    influence on, of blending, 179 *seq.*
      of method of oven-charging, 204 *seq.*
      of moisture in coal, 210 *seq.*
      of rate of heating oven, 213 *seq.*
      of size of coal, 195 *seq.*
  qualities of, and specification, 1, 11, 141 *seq.*
Coke, quenching of, 222 *seq.*
    by the Greensmith quencher, 225
    central, 224, 235
    dry, 225
    on coke car, 222, 223
    on inclined bench, 222
  reactivity of, 117 *seq.*
    early observations on, 117
    effect on, of method of oven-charging, 207, 208
      of rate of heating oven, 218, 219, 220
      of size of coal charged, 202
    influence of, on hearth temperatures, 121
    measurement of, 120 *seq.*
    Midland Coke Research Committee's furnace test for, 126 *seq.*
    significance of, in blast-furnace practice, 117, 139, 140
    with carbon dioxide, 11, 17, 133, 134, 135, 138, 139
    with oxygen, 11, 17, 132, 133, 138, 139
  real density of, 11, 14, 15, 64, 65, 66, 69, 72
    effect on determination of, of different wetting liquids, 66
      of fine grinding of coke, 66
    effect on, of size of coal charged, 201
  sale of, to specification, 141
  sampling of, at blast furnace, 112, 113
    for analysis, 57
    for shatter test, 109, 111 *seq.*
    from coke car, 112
    from conveyor, 112
    from inclined bench, 112
    from oven, 195
  screening and handling of, 226, 227
  sections of, 14, 33, 45
    preparation of, 53 *seq.*
  shape of, 12, 33, 43
  shatter index of, 17, 46, 52, 75, 82, 88, 100 *seq.*
    effect on, of early treatment of coke, 110, 111
      of position of coke in oven, 108, 109, 110
      of size of coke used, 107, 108
  shatter indices of, and caking indices of coals, 168, 169
    average deviation of, 101, 102, 103
    blocky and prismatic, 105
    influence on, of graded sizes of coal, 196
      of through sizes of coal, 198
    linear relationship of, 104
    lists of, 114, 115
    normal relationship between, 116
    range of, 103
    significance of, 100, 101, 116, 169
  shatter test for, 16, 17, 22, 57, 94 *seq.*, 141
  size analyses of, 12, 26, 57
  size of, 11, 18 *seq.*

Coke, size of, effect on, of dropping from different heights, 28, 29, 30
      of mechanical treatment after manufacture, 25, 26
    factors influencing, 20
    influence of, on attrition in blast furnace, 30, 31, 32
      on reactivity with carbon dioxide, 138, 139
      on reactivity with oxygen, 138, 139
      on temperature of combustion, 138, 139
    influence on, of blending coal-charge, 22, 40
      of coking quality of coal, 20
      of graded sizes of coal, 196
      of method of oven-charging, 24, 205
      of rate of heating oven, 24, 25, 214, 215
      of through sizes of coal, 197
  South Wales, 12, 43, 44, 103, 114, 115
  specification of, 1, 11, 141 *seq.*
    and chemical properties, 142 *seq.*
    and hardness, 147, 148
    and porosity, 148
    and reactivity, 148
    and size, 149
    and structure, 148
    and sulphur content, 148
  sponginess of, 101
  stability factor for, 76, 77, 78, 82
  stages in formation of, 171
  structure of, 11, 12, 33 *seq.*, 45
    and method of oven-charging, 206, 207
  sulphur in, determination of, 61
  surface hardness of, 73
  temperature of combustion of, average, 136, 137
    maximum, 135, 136
  Trommel test for, 79, 80, 81
  true abrasion test for, 15, 86 *seq.*
    compared with drum test, 86, 87, 88
  tumbler tests for, 15, 16, 57, 73 *seq.*
    American, 75 *seq.*
    British, 74
    French, 81, 82
    German, 79, 80, 81
  useful size of, in blast furnace, 19
  volatile matter in, determination of, 60
  Westphalian, 18, 114, 115
  Yorkshire, 12, 43, 44, 103, 114, 115
Coke car, quenching at, 222, 223
  sampling from, 112
Coke-oven practice, and size of coal used, 195, 196
Coking coals, 153, 154, 196
  critical maximum size for, 199
  ultimate analysis of, 165
Coking power of coal, 175
Coking test for coal, 175, 176, 177, 178
Coking time, influence on, of moisture in coal charge, 210, 212
    of width of oven, 24
Combustibility of coke, 14, 52, 55, 67, 71, 72, 120
Combustibility of coke, influence on, of porosity of coke, 72
    of rate of combustion, 125
    of size of coke, 123
  test for, 55, 57
Combustion, maximum temperature of, 135, 136
    influence on, of density of coke, 136
      of total porosity of coke, 136
Combustion temperature of coke, 218, 219, 220
Constitution of coal, 154 *seq.*
Contamination of sample during pulverising, 58
Continental practice in blending, 179
Contraction of coal on heating, 172, 173, 174
Conveyor, sampling from, 112
Crushed large coal, 186, 187
  slack, 186, 187
Crushing strength of coke, 11
Cumberland cokes, 103, 114, 115
Cuticles in coal, 156, 162

D

Degree of fissuring, 14, 44, 47, 101
Degree of hardness, 47
Density of coke, apparent, 64 *seq.*, 71
  effect on, of graded sizes of coal, 201
    of method of oven-charging, 206, 207
    of rate of oven-heating, 218, 219
    of size of coal, 201
  its influence on maximum temperature of combustion, 136
  real, 64 *seq.*, 72
    determination of, 69
      effect on, of different wetting liquids, 66
      effect on, of fine grinding of coke, 66, 201
Derbyshire, cokes, 12, 29, 30, 44, 103, 114, 115
  coking coals, 164, 165
    ultimate analysis of, 165
Determination, of apparent density, 67, 68
  of apparent porosity, 68, 69
  of arsenic, 62
  of ash, 55, 60
  of bulk density, 70, 71
  of carbon, 62
  of moisture, 55, 56, 57, 60
  of nitrogen, 61
  of phosphorus, 61
  of real density, 69, 79
  of sulphur, 61
  of total porosity, 70
  of volatile matter, 60
Deviation, average, of shatter indices, 101, 102, 103
Direct reduction in blast furnace, 118, 119
Drum tests for coke, 73 *seq.*
Dry quenching of coke, 225
Duplication of results in shatter test, 98, 99
Durain in coal, 163

Durham, cokes, 12, 43, 44, 103, 114, 115
  coking coals, 164, 165, 166
    ultimate analysis of, 165, 166
Dust, 23
  rich in fusain, use of, 189, 190, 191

E

Efficiency of screening, 11
Estimation of fusain, 188
Expansion of coal, 172 *seq.*
  its influence on quality of coke, 178
Experimental oven tests, 231
  compared with full-scale oven tests, 232

F

Factors influencing, the rate of heating of ovens, 213
  the size of coke, 20
Final expansion of coal, temperature of, 175
Final plasticity of coal, 171
Fine crushing of coal, 22, 197, 202
  compared with coarse crushing, 198
  value of, 201
Fingery coke, 22, 97, 104, 105
Fissuring, degree of, 44, 101
Flue temperatures, 24, 108, 109, 110
Formation of breeze, 27, 28, 30, 33, 222, 226, 227
Formation of coal, 156, 158 *seq.*
  peat-to-anthracite, theory of, 156
    analytical evidence for, 157
    chemical evidence for, 157
    microscopical evidence for, 156
Formation of coke, stages in, 171 *seq.*
Formation of fissures in coke, 173
Formation of slag in blast furnace, 143
Foundry cokes, 37
Fractures in coke, 13, 14, 33, 34, 35, 44, 46, 52
French, fat coals, 179
  lean coals, 179
  tumbler tests, 81, 82
Friability of anthracite duff blends, 184
Fuel bed, average temperature of, 136, 137
Full-oven tests, 228
  compared with bag tests, 231
  compared with box tests, 230
  compared with experimental oven tests, 232
  disadvantages of, 228
Fusain, 23, 42, 163, 186 *seq.*
  blending of coking coals with, 186 *seq.*
  blending with finely ground, 191, 192
  blending with "pure," 191, 192
  diluted with coal dust, use of, 192, 193
  estimation of, 188
  influence of, on coke quality, 188
  substitutes, use of, in blending, 193
  use of dust rich in, 189, 190

G

Gas coals, Westphalian, 179
Gas works practice, and size of coal used, 195
German tumbler tests, 79, 80, 81
Good coking coals, 167
Graded sizes of coal, 195, 196
  their influence, on density of coke, 201
    on porosity of coke, 201
    on size of coke, 196
    on strength of coke, 196
Greensmith quencher, 225
Grinding of coal, coarse, 202
  fine, 202

H

Handling of coke, 226, 227
Hardness number, 16, 74 *seq.*, 82, 100, 101, 102
Hardness of coke, 11, 14, 73, 74, 94 *seq.*, 107
  and specification, 147, 148
  influence on, of method of over-charging, 205, 206
    of rate of oven-heating, 216, 217
Hearth temperatures and reactivity of coke, 121
High-temperature coke breeze blends, 193
Hydrogen contents of coking coals, 166

I

Impact hardness of coke, 11, 16, 73, 94 *seq.*
Inclined bench, quenching at, 222
  sampling from, 112
Index, caking, 168, 169
  and shatter index, 168, 169
Index, shatter, 46, 169
Influence of fusain, 188
Initial contraction of coal, temperature of, 173, 175
Initial expansion of coal, temperature of, 175
Initial plasticity of coal, 171

L

Laboratory coking test for coals, 175 *seq.*
Lancashire cokes, 103, 114, 115
Law of heat compression, 136
Lean coals, Belgian, 179
  French, 179
Lignin in coal, 161
Lignitous coal, 156, 159, 160
Linear relationship of shatter indices, 104
Longitudinal, fractures in coke, 13, 44
  sections, 47
Low-temperature coke, 23, 42, 181, 184
  blending of, with coking coals, 40, 184 *seq.*
Low volatile coals, 42, 180
  blending of, with coking coals, 183 *seq.*

M

Macro-structure of coke, 45, 52
Manganese steel mortar, 58
Maximum temperature of combustion, 135, 136
  influence on, of density of coke, 136
    of porosity of coke, 136
Mechanical strength index of coke, 167
Meiler coke, 117, 140
Method of oven-charging, its influence, on abradability of coke, 206
    on density of coke, 206
    on hardness of coke, 205, 206
    on porosity of coke, 206
    on quality of coke, 204 *seq.*
    on reactivity of coke, 207, 208
    on size of coke, 24, 205
    on structure of coke, 206, 207
    on throughput, 204
Method of pulverising coke, 58
Methods of research on coke, 228 *seq.*
Microscopical evidence for peat-to-anthracite theory of coal formation, 156
Micro-pores, 14
Micro-structure of coke, 45, 52
Micum tests, 73, 80, 81, 141
Moisture, determination of, 55, 56, 57, 60
Moisture in coal charge, and smoke abatement, 210
  its influence on coking time, 210, 212
  its influence on quality of coke, 210 *seq.*
Moisture in coke, and blast-furnace working, 142 *seq.*

N

Nitrogen, determination of, 61
Non-caking coal, 154
Non-coking coals, 154, 167, 175
  blending of, with coking coals, 179, 180
  Westphalian, 179

O

Open pores, 14
Oven, average rates of heating of, 213, 214
  cake charging of, 204
  factors influencing rate of heating of, 213
  method of charging of, its influence, on abradability of coke, 205, 206
    on density of coke, 206, 207
    on hardness of coke, 205, 206
    on porosity of coke, 206, 207
    on quality of coke, 204 *seq.*
    on reactivity of coke, 207, 208
    on size of coke, 205
    on structure of coke, 206, 207
    on throughput, 204
  rate of heating of, its influence, on density of coke, 218, 219
    on combustion temperature of coke, 218, 219, 220
    on hardness of coke, 216, 217, 218
Oven, rate of heating of, its influence on porosity of coke, 218, 219
    on quality of coke, 213
    on reactivity of coke, 218, 219, 220
    on size of coke, 214, 215
  sampling of coke from, 195
  top charging of, 204
  width of, 43
Oxygen content of coking coals, 166
Oxygen, reactivity of coke with, 11, 17, 132, 133

P

Peat-to-anthracite theory of coal formation, 156, 158
  analytical evidence for, 157
  chemical evidence for, 157
  microscopical evidence for, 156
Percentage expansion of coal, and quality of coke, 178
Phosphorus, determination of, 61
Plasticity of coal, 171
  initial, 171
  final, 171
Plastic range for coking coals, 213
Poor coking coals, 167
Poorly caking coals, 37
Pore structure of coke, 14, 52
Porosity of coke, 11, 15, 64, 66, 67, 69, 70, 71, 72
  and combustibility, 72
  and hardness, 72
  and maximum temperature of combustion, 136
  and specification, 148
  influence on, of method of oven-charging, 206, 207
    of rate of heating oven, 218, 219
    of size of coal, 201
Position of coke in oven, and its hardness, 108, 109, 110
Power, agglutinating, of coal, 153, 154, 164, 168 *seq.*
  caking, of coal, *see* agglutinating.
Preparation of coke sections, 53
Prismatic coke, 97, 104, 105, 116
Production of coke, 1
Proximate analysis of coal, 2
Pulverising of coke, for analysis, 58
  and ash content, 58
  and contamination of sample, 58
Purity of coke, 11

Q

Qualities of coke, specification of, 1, 11, 141 *seq.*
Quality of coke, influence on, of blending, 179 *seq.*
    of carbon content of coal used, 166
    of method of oven-charging, 204 *seq.*
    of moisture in coal, 210 *seq.*
    of percentage expansion of coal 178
    of rational analysis of coal, 167
    of rate of heating oven, 213 *seq.*
    of size of coal, 195 *seq.*

Quenching of coke, 222 *seq.*
  by the Greensmith quencher, 225
  central, 224, 225
  dry, 225
  on coke car, 222, 223
  on inclined bench, 222

R

Range of shatter indices, 103
Rate of heating oven, average, 213, 214
  factors influencing, 213
  its influence, on density of coke, 218, 219
    on combustion temperature of coke, 218, 219, 220
    on hardness of coke, 216, 217, 218
    on porosity of coke, 218, 219
    on quality of coke, 213 *seq.*
    on reactivity of coke, 218, 219, 220
    on size of coke, 24, 214, 215
Rate of combustion of coke, and combustibility, 125
Rational analyses of coals, 2, 166
  influence on quality of coke produced, 167
Reactivity of coal, 163, 164
Reactivity of coke, 117 *seq.*
  early observations on, 117
  effect on, of method of oven-charging, 207, 208
    of rate of heating oven, 218, 219, 220
    of size of coal charged, 202
  influence of, on hearth temperatures, 121
  measurement of, 120 *seq.*
  Midland Coke Research Committee's furnace test for, 126 *seq.*
  significance of, in blast-furnace practice, 117, 139, 140
  with carbon dioxide, 11, 17, 133, 134, 135, 138, 139
  with oxygen, 11, 17, 132, 133, 138, 139
Reactivity of ulmins, 167
Real density of coke, 11, 14, 15, 64, 65, 66, 69, 72
  effect on, of different wetting liquids, 66
    of fine grinding, 66
Resins in coal, 156, 161, 162, 163, 167
Resistant plant tissues in coal, 156, 161, 162, 163, 167

S

Salamander test, 122
Sale of coke to specification, 141 *seq.*
Sampling of coke, at blast furnace, 112, 113
  for analysis, 57
  for shatter test, 109, 111 *seq.*
  from coke car, 112
  from conveyor, 112
  from inclined bench, 112
  from oven, 195
Screening efficiency, 11
Screening of coke, 226, 227
Sections of cokes, 14, 33, 45
  preparation of, 53 *seq.*
Shale in coking slacks, 199, 200
  as points of weakness, 200, 201
Shape of coke, 12, 33, 43
Shatter indices of cokes, 46, 52, 75, 82, 88
  and caking indices of coals, 168, 169
  average deviation of, 101, 102, 103
  blocky and prismatic, 105
  effect on, of early treatment of coke, 110, 111
    of position of coke in oven, 108, 109, 110
    of size of coke used, 107, 108
  influence on, of graded sizes of coal, 196
    of through sizes of coal, 198
  linear relationship of, 104
  lists of, 114, 115
  normal relationship between, 116
  range of, 103
  significance of, 100, 101, 102, 116, 169
Shatter test for coke, 16, 17, 22, 55, 57, 94 *seq.*, 141
  apparatus for, 95
  duplication of results in, 98
  origin of, 94
  sampling of coke for, 109, 111 *seq.*
  standard screens for, 96
  statement of results from, 97
  tolerated deviation in, 97
  usefulness of, 116
Shrinkage, 13, 25, 42
Size analyses of coals charged in practice, 199, 200
Size analyses of cokes, 12, 57
Size of coal charged, its influence, on density of coke, 201
    on porosity of coke, 201
    on quality of coke, 195 *seq.*
    on reactivity of coke, 202
Size of coke, 11, 18
  effect on, of dropping from different heights, 28, 29, 30
  factors influencing, 20
  influence of, on attrition in blast furnace, 30, 31, 32
    on abrasion, 85, 86
    on reactivity with carbon dioxide, 138, 139
    on reactivity with oxygen, 138, 139
    on shatter index, 107, 108
    on temperature of combustion, 138, 139
  influence on, of blending coal charge, 22, 40
    of coking quality of coal, 20
    of graded sizes of coal, 196
    of method of oven-charging, 24, 205
    of rate of heating oven, 24, 25, 214, 215
    of through sizes of coal, 197

Slacks, coking, critical maximum size of, 199
Slag formation in blast furnace, 143
Slurry, 23, 42, 52, 186
  coke from, 186, 187
  use of, in coking, 190, 191
Smoke abatement, and moisture in coal charged, 210
Softening temperatures of coal, 171
Soluble constituents in bituminous coal, 161, 162
Solution loss in blast-furnace, 117, 118
South Wales, cokes, 12, 43, 44, 103, 114, 115
  coking coals, 164, 165, 166
    ultimate analyses of, 165
Specification of coke, 1, 141 *seq.*
  and chemical properties, 142 *seq.*
  and hardness, 147, 148
  and porosity, 148
  and reactivity, 148
  and size, 149
  and structure, 148
  and sulphur content, 148
Sponginess of coke, 101
Spore exines in coal, 156, 161, 162
Stability factor, 76, 77, 78, 82
Stages in formation of coke, 171 *seq.*
Standard screens, 96
Steam coals, 2, 153, 166
Structure of coke, 11, 12, 33 *seq.*, 45, 52
  and method of charging, 206, 207
  and specification, 148
Sulphur content of coke, and specification, 148
Sulphur, determination of, 61
Surface hardness, 73

T

Tar yield and coal composition, 2, 164
Temperature, average, in fuel bed, 136, 137
Temperatures, flue, 24
Temperatures in hearth, and reactivity of coke, 121
Temperature of combustion, effect on, of density of coke, 136
    of size of coke, 138, 139
    of total porosity of coke, 136
  maximum, 135, 136
Temperature of initial contraction of coal, 173, 174, 175
Temperature, of initial expansion of coal, 173, 174, 175
  of final expansion of coal, 175
Temperatures, softening, of coal, 171
Tests for caking power, 168, 169
Through sizes of coal, 195
  influence of, on size of coke produced, 197
    on strength of coke produced, 198
Throughput and method of charging, 204
Tolerated deviation in shatter test, 97
Top-charging, 24, 52, 204, 208, 209
Transverse fractures in coke, 13, 44
Transverse sections, 47
Trommel tests, 79, 80, 81
True abrasion test for coke, 15, 86 *seq.*, 91 *seq.*
Tumbler tests for coke, 15, 73 *seq.*
  American, 75 *seq.*
  British, 74
  French, 81, 82
  German, 79, 80, 81

U

Ulmin compounds in coal, 161, 162, 163
Ultimate analysis of coal, 2, 164, 165, 166
Usefulness of shatter test, 116
Useful size of coke in blast furnace, 19

V

Vitrain in coal, 163
Volatile matter in coal, 154, 165, 166
  determination of, 60

W

Waxes in coal, 161, 162, 163, 167
Westphalian, coke, 18, 114, 115
  coking coals, 179
  gas coals, 179
  non-coking coals, 179
Width of oven, and coking time, 24, 43
  and length of coke pieces, 11, 12
Wood charcoal, 117, 140

Y

Yorkshire, cokes, 12, 28, 43, 44, 103, 114, 115
  coking coals, 164, 166

UNIVERSITY
COLLEGE
LIBRARY
NOTTINGHAM